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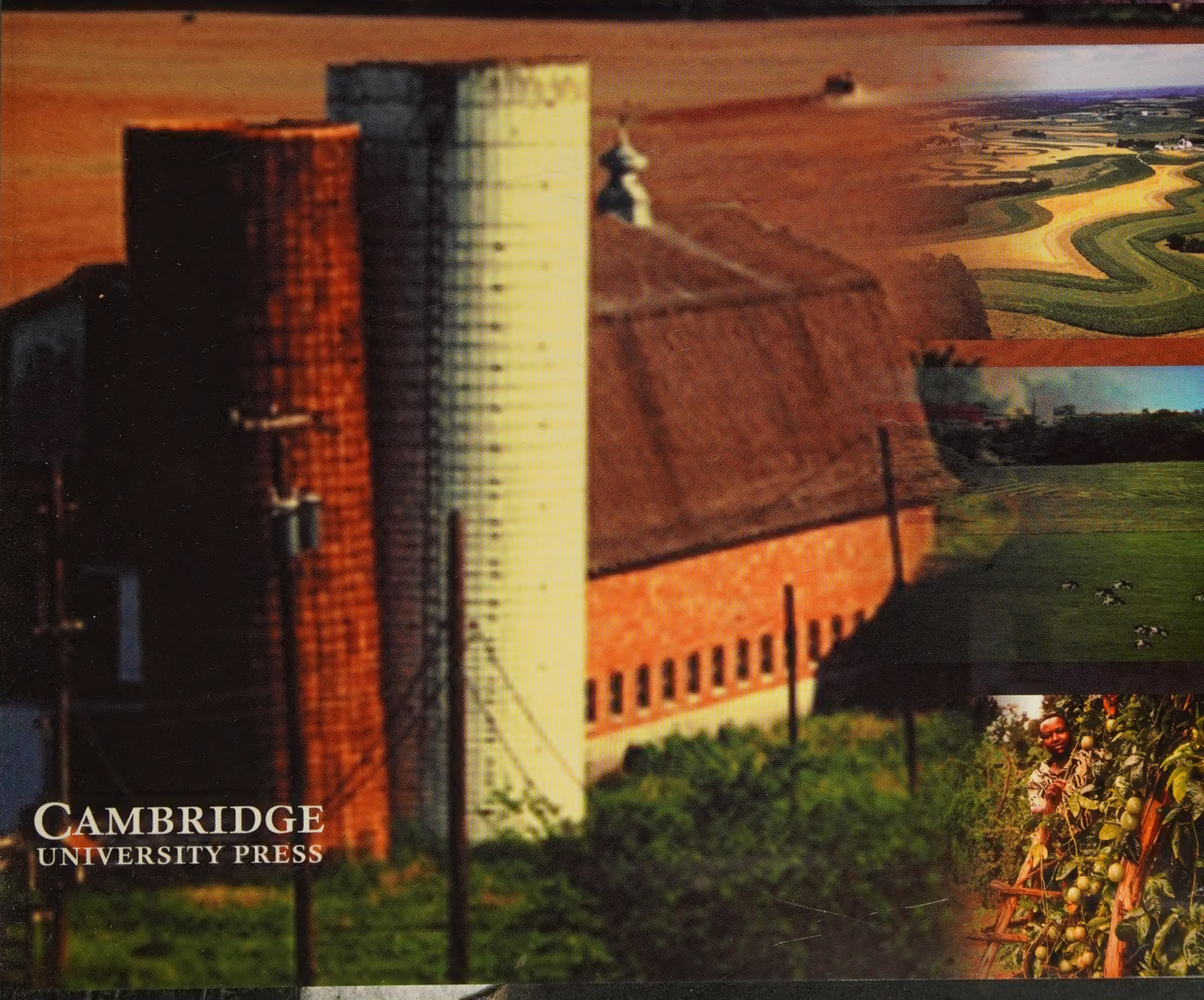

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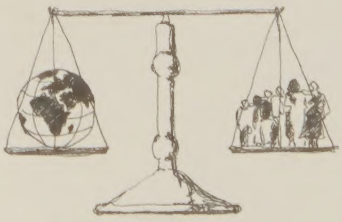

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Feed intake, growth rate and some anatomical characteristics of broilers fed commercial diets supplemented with green feeds

I. Etela[1,*], G.A. Kalio[2], A. Monsi[3], and E.V. Ezieshi[4]

[1]Department of Animal Science and Fisheries, University of Port Harcourt, East-West Road, Choba, PMB 5323, Port Harcourt, Rivers State, Nigeria.
[2]Department of Agriculture, Rivers State College of Education, Ndele, Nigeria.
[3]Rivers State University of Science and Technology, Port Harcourt, Nigeria.
[4]Department of Animal Science, University of Benin, Benin City, Nigeria.
*Corresponding author: i.etela@uniport.edu.ng or ibetela@yahoo.com

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Abstract

A study was conducted on the Teaching and Research Farm of the Rivers State University of Science and Technology, Nigeria to evaluate the nutritional suitability of four treatments, namely a commercial type broiler diet as compared with the commercial diet supplemented with either fresh centrosema (*Centrosema molle*), pueraria (*Pueraria phaseoloides*), or waterleaf (*Talinium triangulare*) leaves. These diets were fed to 120 day-old chicks (Lohmann Brown) over a 62-day period with treatments arranged in a completely randomized design (CRD). Chemical composition of broiler basal diets differed significantly from the three green foliage supplements. Dry matter (DM) of leaf meals ranged from 97.8 to 227.0 g kg^{-1} which was significantly ($P < 0.05$) lower than that of broiler basal diets which averaged 900 g kg^{-1}. Crude protein (CP) of leaf meals, however, ranged from 182.0 to 244.0 g kg^{-1} which was generally higher than basal diets (130–153 g kg^{-1}). Similarly, crude fiber (CF) was highest for centrosema and pueraria leaves (330–342 g kg^{-1}) and lowest in basal diets (164–222 g kg^{-1}). However, ether extract (EE) and nitrogen-free extract (NFE) were significantly higher in broiler basal diets. Broiler daily and total feed intake over 62 days were similar between treatments and the control, averaging 112 g d^{-1}, while diets containing waterleaf were slightly (2.5%) lower. Total and daily bodyweight (BW) gains (2110 g and 34 g d^{-1}) were also similar between treatments and the control, except that gains where the broiler diet was supplemented with centrosema foliage were 2.9% higher. A higher feed conversion ratio (FCR) and lower protein efficiency ratio (PER) for the diet supplemented with pueraria indicates a higher feed efficiency and better protein efficiency in the commercial control diet. Carcass characteristics with the commercial control diet included greater ($P < 0.05$) intestinal length and gizzard and spleen weights than with green foliage supplements. However, broiler carcass weight was generally lowest ($P < 0.05$) in the control group (64.3 g/100 g BW) and highest in the waterleaf group (71.3 g/100 g BW). Small differences in carcass weight among the treatments tested reduces the effectiveness of green feeds for practical and economic intensive broiler production. However, increased effectiveness of green feed supplementation for broiler production might likely be observed where broilers are managed on fenced rangelands planted to selected green feeds or in integrated systems where other livestock (rabbits, sheep, goats, etc.) are jointly reared. These results support the recommendation that leaf meals of green feeds should be incorporated into broiler diets in future studies.

Key words: broilers, carcass yield, green feeds, organ characteristics

Introduction

Among major factors that hinder the development of commercial poultry production are short supplies and high prices of available commercial type poultry diets. Recent studies observed that feed cost accounts for between 60% of total cost of broiler production in Nigeria[1] and 70% in Cameroon[2]. Thus, a combination of high ingredient costs

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and limited availability of conventional feed ingredients have resulted in the production of poultry feeds that are mostly of questionable quality. As a result, most feeds often failed to satisfy the needs of poultry farmers in terms of nutrients supplied compared to the nutritional requirements of the birds. Intensive broiler management systems tend to deprive birds of free access to fresh pastures and succulent leguminous plants that are readily available to scavenging chicken around homesteads and villages. These resources appear not to have been amply investigated as local feed resources for poultry production even though they are believed to contain reasonable levels of certain valuable nutrients.

Williamson and Payne[3] observed that supplementing maize-based diets with fresh green feeds containing high crude protein (CP) (173–220 g kg^{-1} DM) could contribute significantly to meeting the protein requirements of broilers for growth. Thus, a good knowledge of the nutritional value of such plants in poultry nutrition would be valuable, especially for the ones that grow easily with simple agronomic practices. Full use of these green feeds could improve quality as well as reduce total feed cost under intensive poultry production. Therefore, the purpose of this study was to evaluate the effects of supplementing commercial type broiler diets with selected fresh green feeds on the performance of broilers. Specifically, the study aimed at: (1) evaluating the value of centrosema, pueraria, and waterleaf as supplemental feed resources to broiler diets, and (2) determining their possible effects on some carcass characteristics of broilers.

Materials and Methods

Site of experiment and treatments

The experiment was conducted at the Rivers State University of Science and Technology Teaching and Research Farm in Port Harcourt, Nigeria (a humid forest zone) with the birds housed in a half-walled deep-litter poultry house. Each pen measured about 1 × 3 m with diurnal temperature ranging between 28 and 32°C. The commercial type broiler diets were purchased from a local dealer while the fresh green feeds (centrosema, pueraria and waterleaf) introduced as supplements were harvested from already growing crops within the University Teaching and Research Farm premises. There were four dietary treatments, namely: Treatment I (commercial type broiler diet only; as control), Treatment II (commercial type broiler diet + fresh centrosema leaves), Treatment III (commercial type broiler diet + fresh pueraria leaves) and Treatment IV (commercial type broiler diet + fresh waterleaf leaves).

Birds and experimental design

One hundred and twenty day-old broilers (Lohmann Brown), procured from local dealers, were randomly allocated into 12 groups, each comprising ten birds. Treatments were arranged in a completely randomized design (CRD) with three replicates per group. Each replicate of ten birds was housed in a 1 × 3 m half-walled pen. The commercial type broiler diets and fresh green feeds were introduced to the pens simultaneously on a daily basis. Commercial type broiler starter diet was fed from day-old to 5 weeks and followed by broiler finisher diet from 6 to 10 weeks of age. Bundles of fresh green feed supplemental treatments, weighing about 50–300 g per replicate of ten birds, were hung daily in each pen at about 10–45 cm above the floor of the pen, which was adjusted as the birds grew older to ensure about 10% daily leftovers. Birds were monitored for feed intake and weighed, individually, at the start of the experiment and at weekly intervals. Feed conversion ratios (FCRs) and protein efficiency ratios (PERs) (ratio of weight gain to protein intake) were then computed. Two birds per replicate were, randomly, selected at the end of the 62-day experimental period, weighed and sacrificed by cervical dislocation to determine relative intestinal length, gizzard, liver, spleen, kidney and carcass weights.

Chemical and statistical analyses

Proximate composition of both the commercial type broiler diets and green feeds was carried out according to the prescribed methods[4]. Results were subjected to analysis of variance (ANOVA) to determine differences among treatment means according to the procedures described[5]. Where differences were significant, mean separation was done using the least significant differences (LSD) option at the 5% level of probability.

Results

Table 1 showed higher dry matter (DM) and crude fiber (CF) contents in centrosema (215.0 and 342.0 g kg^{-1} DM) and pueraria (227.0 and 330.0 g kg^{-1} DM) than in waterleaf (97.8 and 111.0 g kg^{-1} DM), respectively. The ash content of waterleaf (352.0 g kg^{-1} DM) was significantly ($P < 0.05$) higher than those of centrosema (81.0 g kg^{-1} DM), pueraria (78.0 g kg^{-1} DM) and the commercial type broiler diets (53.8 g kg^{-1} DM for starter and 103.8 g kg^{-1} DM for finisher). Similarly, ether extract (EE) and nitrogen-free extract (NFE) ranged from the lowest (15.0 and 317.0 g kg^{-1} DM) for waterleaf to the highest (40.0 and 478.1 g kg^{-1} DM) for the starter diet, respectively. The CP content of pueraria (244.0 g kg^{-1} DM) was significantly ($P < 0.05$) higher than those of both centrosema (182.0 g kg^{-1} DM) and waterleaf (205.0 g kg^{-1} DM).

Feed intake ranged ($P < 0.05$) from lowest (110.2 g d^{-1}) for waterleaf group to highest (114.1 g d^{-1}) for centrosema group (Table 2). Similarly, final bodyweight (BW) and BW gain (BWG) were significantly different ($P < 0.05$), with the control group recording the lowest values (2173 g and 33.4 g d^{-1}) and the centrosema group recording the highest values (2263 g and 35.0 g d^{-1}), respectively. The FCR and PER both gave significant differences ($P < 0.05$)

Table 1. Proximate analysis and metabolizable energy contents of proprietary diet, and centrosema, pueraria and waterleaf foliage.

Constituent	Broiler starter	Broiler finisher	Centrosema foliage	Pueraria foliage	Waterleaf foliage	Mean	SEM[1] (df = 15)
Dry matter (DM) (g kg^{-1})	888.4^{a}	904.7^{a}	215.0^{b}	227.0^{b}	97.8^{b}	466.6	177.00
	---------- Proximate composition as percent of DM ----------						
Ash (g kg^{-1} DM)	53.8^{b}	103.8^{b}	81.0^{b}	78.0^{b}	352.0^{a}	133.7	55.14
CP (g kg^{-1} DM)	153.0^{cd}	130.5^{d}	182.0^{bc}	244.0^{a}	205.0^{ab}	182.9	19.83
CF (g kg^{-1} DM)	163.5^{bc}	222.1^{b}	342.0^{a}	330.0^{a}	111.0^{c}	233.7	45.34
EE (g kg^{-1} DM)	40.0^{a}	39.1^{a}	21.0^{b}	34.6^{a}	15.0^{c}	29.9	5.05
NFE (g kg^{-1} DM)	478.1^{a}	409.2^{ab}	374.0^{ab}	320.0^{b}	317.0^{b}	307.7	70.88
Metabolizable energy (MJ kg^{-1})	12.0	9.7	ND	ND	ND	ND	ND

[1] SEM, standard error of mean.
ND, not determined.
[a–d] Means with the same superscripts in the same row are not significantly different ($P>0.05$).

Table 2. Effects of foliage from centrosema, pueraria and waterleaf on feed intake, bodyweight (BW) changes, FCR and PER of broilers after 62 days.

Parameter	Broiler diets (control)	Control + fresh centrosema	Control + fresh pueraria	Control + fresh waterleaf	Mean	SEM[1] (df = 8)
Total feed intake (g)	6968^{ab}	7075^{a}	6945^{bc}	6830^{c}	6955	50.2
Daily feed intake (g)	112.4^{ab}	114.1^{a}	112.0^{bc}	110.2^{c}	112.2	0.80
Initial BW (g)	101^{a}	95^{b}	103^{a}	104^{a}	101	2.0
Final BW (g)	2173^{b}	2263^{a}	2203^{b}	2193^{b}	2208	19.4
Total BW gain (BWG) (g)	2072^{b}	2168^{a}	2100^{b}	2098^{b}	2110	20.5
Daily BWG (g)	33.4^{b}	35.0^{a}	33.9^{b}	33.7^{b}	34.0	0.35
FCR	3.26^{b}	3.26^{b}	3.31^{a}	3.27^{b}	3.28	0.012
PER	2.10^{a}	1.69^{ab}	1.24^{c}	1.49^{bc}	1.63	0.182

[1] SEM, standard error of mean.
[a–c] Means with the same superscripts in the same row are not significantly different ($P>0.05$).

Table 3. Effects of foliage from centrosema, pueraria and waterleaf on some carcass characteristics of broilers after 62 days expressed per 100 g bodyweight (BW).

Anatomical characteristics	Broiler diets (control)	Control + centrosema	Control + pueraria	Control + waterleaf	Mean	SEM[1] (df = 8)
Carcass weight (g/100 g BW)	64.3^{b}	69.3^{a}	68.0^{ab}	71.3^{a}	68.2	1.47
Intestinal length (mm/100 g BW)	110.53^{a}	97.38^{b}	92.63^{b}	88.61^{b}	97.29	4.764
Gizzard weight (g/100 g BW)	3.32^{a}	3.04^{b}	3.04^{b}	2.96^{b}	3.09	0.079
Liver weight (g/100 g BW)	1.98^{b}	1.64^{b}	2.40^{a}	1.77^{b}	1.93	0.172
Kidney weight (g/100 g BW)	0.82^{a}	0.66^{b}	0.88^{a}	0.80^{a}	0.79	0.047
Spleen weight (g/100 g BW)	0.111^{a}	0.085^{c}	0.096^{bc}	0.108^{ab}	0.100	0.0060

[1] SEM, standard error of mean.
[a–c] Means with the same superscripts in the same row are not significantly different ($P>0.05$).

among treatments, ranging from 3.26 to 3.31 and from 1.24 to 2.10, respectively.

The effects of centrosema, pueraria, and waterleaf on some carcass characteristics of broiler chickens (all adjusted to percent of BW) are shown in Table 3. Carcass weight ranged ($P<0.05$) from 64.3 g/100 g BW for control to 71.3 g/100 g BW for waterleaf group. Significant differences ($P<0.05$) were recorded for intestinal length (88.61–110.53 mm/100 g BW) and gizzard weight (2.96–3.32 g/100 g BW). Similarly, liver and kidney weights differed ($P<0.05$), with the centrosema group recording the least (1.64 and 0.66 g/100 g BW) and the pueraria group recording the highest (2.40 and 0.88 g/100 g BW) values, respectively. Spleen weight varied ($P<0.05$) between 0.085 g/100 g BW for the centrosema group and 0.111 g/100 g BW for the control group.

Discussion

The ash and EE contents recorded for centrosema (Table 1) were lower while those for pueraria were within the ranges reported earlier (Lawal and Sodeinde[6]). The same authors also reported lower CP, but similar NFE, contents in both centrosema and pueraria. Also, the recorded CF contents were within the range reported for centrosema but lower than the reported values for pueraria[6]. The mean recorded CP contents for the commercial type starter and finisher broiler diets used for the study were grossly below the recommended CP levels of 21.0–23.0% and 19.0–19.5%, respectively, for broilers in the tropics[7–9].

Fresh green feeds have been reported to add succulence to feed, stimulate appetite, supply protein, minerals and vitamins[10], and could contribute significantly to improved performance of birds. The recorded daily feed intakes were higher than some published values[11–13] but relatively lower than those reported by others[1,14]. Similarly, the mean daily BWG was higher than reported by some[12,15–17], similar to the value by Awosanya and Abikoye[11], but lower than others[1]. The recorded FCRs were higher than observed ranges by others[1,16,18] but much lower than reported by Uchegbu et al.[17] Higher FCR reflects lower feed efficiency since more feed is required per unit BWG. The variations in PER indicated that protein in the control diet was superior to that in the green feeds. Among the green feeds, the protein in centrosema and waterleaf gave similar and better BWG than that in pueraria, which was the least effective at being converted to meat.

The organ weights were adjusted for BW (as percent) as suggested by Daghir and Pellet[19] for a more objective comparison. The slight differences in carcass weight among treatments renders the use of the green feeds not very valuable for practical intensive broiler production purposes. Another disadvantage is that the proposition may not be economical in the circumstances, considering the labor intensive nature of green feeds collection. The recorded carcass weights were similar to those reported by Awosanya and Abikoye[11], who evaluated the effects of feeding raw, toasted or cooked pueraria seed in a broiler finisher ration at 20% inclusion level. However, the values were relatively higher than those recorded by some workers (Udedibie et al.[13]) but lower than those by others (Eruvbetine et al.[12]; Udedibie et al.[13]; Uchegbu et al.[17]; Onibi et al.[18]). There was no observable effect of CF (from the green feeds) on both intestinal length and gizzard weight as was earlier reported (Deaton et al.[20]).

Mean gizzard weight was lower than values published by Udedibie et al.[13], similar to those reported by Eruvbetine et al.[12] and Onibi et al.[18] but higher than values published by others[17]. Also, the recorded mean liver weight was lower than the values reported by previous workers[11,15,17], similar to that recorded by Udedibie et al.[13], but higher than that published by Onibi et al.[18] The recorded mean kidney values were relatively higher than mean values reported earlier by other workers except for the centrosema group where it was lower[12,17,18].

The trial did not find much addition to economic benefit resulting from the use of the green feeds as fresh supplemental resources. Furthermore, synthetic vitamins and minerals are also available in their pure forms that could be used more economically and efficiently than fresh green feeds. There may be better effects if the forage from centrosema, pueraria and waterleaf were evaluated for scavenging backyard rearing systems or as a major proportion of the ration under restricted commercial type diet intake. Other conditions under which the benefits might easily be observed would be when planted on pasturelands for scavenging broilers, as is attainable under an extensive or semi-intensive production system as is peculiar with village chicken production system.

This could be achieved, possibly, by managing the broilers on fenced rangelands planted with pure stands of the selected green feeds. Furthermore, such a system would support diversification of production where other domestic livestock (such as rabbits, sheep and goats) could be reared jointly in an integrated production system thus guaranteeing agricultural sustainability. However, from an economic point of view this may also not be profitable; moreover, the birds can scarcely consume such a quantity of the green feeds that will sustain them except when the dried leaf meals are incorporated into their diets.

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Innovative strategies for on-farm weed management in organic carrot

Andrea Peruzzi[1,*], Marco Ginanni[2], Marco Fontanelli[1], Michele Raffaelli[1], and Paolo Bàrberi[3]

[1]DAGA, University of Pisa, Via S. Michele degli Scalzi 2, 56124 Pisa, Italy.
[2]CIRAA E. Avanzi, University of Pisa, Via Vecchia di Marina 6, 56010 S. Piero a Grado, Pisa, Italy.
[3]Land Lab, Scuola Superiore Sant'Anna, Piazza Martiri della Libertà 33, 56127 Pisa, Italy.
*Corresponding author: aperuzzi@agr.unipi.it

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Abstract

Weed management is often the most troublesome technical problem to be solved in organic farming, especially in poorly competitive crops like vegetables. A four-year (2000–2003) series of trials was established to assess the possibility of adopting an innovative non-chemical weed management system in organic carrot grown on the Fucino plateau, i.e., the most important carrot-growing area in Italy. The system utilized for physical weed control was based first on a false seedbed technique followed by pre-sowing weed removal, performed with a special 2 m wide 6-row spring-tine harrow. Prior to crop emergence, a pass with a flame weeder equipped with four 50 cm wide-open flame burners was also performed. Post-emergence weed control consisted of one or more hoeing passes with a purpose-designed 11-tine precision hoe equipped with spring implements (torsion weeders and vibrating tines), in addition to hand weeding. This innovative system was applied to a novel planting pattern (sowing in ten individual rows within 2 m wide beds) and compared to the standard management system of the area (sowing within 2 m wide beds but in five bands, use of spring-tine harrowing and flame weeding pre-emergence and of traditional hoeing post-emergence). The new system was tested in different commercial farms including both early and late-sown carrot. Assessments included machine operative characteristics, labor time, weed density and biomass, crop root yield and yield quality, and economic data (physical weed control costs and crop gross margin). Compared to the standard system, the innovative system usually resulted in reduced labor time (from 28 to 40%) and total costs for physical weed control (on average $-416\,€\,ha^{-1}$). Use of the precision hoe resulted in intra-row weed reduction ranging from 65 to 90%, which also led to a marked reduction in the labor required for hand weeding. In 2001 the two systems did not differ in terms of yield and yield quality, whereas in 2002 and 2003 the innovative system showed a higher mean density of carrot plants (from 28 to 55%), root yield (from 30 to 42%), and gross margin (from 40 to 100%). Carrot yield was higher in farms which adopted an early sowing whereas root commercial quality was somewhat variable between systems and years. In general, results obtained with the innovative management system look very promising.

Key words: organic carrot, physical weed control, false seedbed technique, spring-tine harrow, flame weeder, hoeing, torsion weeder, hand weeding, labor cost

Introduction

Organic horticulture in Italy, which is spread over roughly 12,500 ha, accounts for 1.3% of the total area under organic cultivation in the country (approximately 1 million ha). If organic potato and pea are included, then the total area rises to roughly 17,000 ha[1].

In the framework of Italian vegetable production, carrot (*Daucus carota* L.) constitutes one of the most representative crops. Italy ranks third among European nations in terms of land devoted to carrot cultivation (after the United Kingdom and France), the crop being grown in Italy on an overall area $>10{,}000\,ha\,yr^{-1}$, with an average yield of roughly $50\,t\,ha^{-1}$. However, the area devoted to organic carrot cultivation plus that under conversion to organic is currently limited to *c.* 400 ha[1]. The most important region for this crop is Abruzzo, which features a vast area (Fucino plateau) under carrot cultivation (roughly $2500\,ha\,yr^{-1}$), grown mainly to be sold as fresh produce, only 10% of the production being sold to industry[2]. Abruzzo carrot

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gives an excellent yield (on average 60–70 t ha^{-1}, for an overall gross saleable production of 10–15 million € yr^{-1}), and excellent product quality, as it is rich in vitamins (in particular ascorbic acid) and mineral elements[2].

The most severe threat that has long created difficulties for carrot growers is that of weeds. This crop has poor ability to compete with weeds, for two main reasons. First, its seeds have very low vigor and thus extremely slow emergence[3]; second, due to its growth typology, the hypogeal part (the taproot) is preferred as the photosynthetate sink during the productive cycle, at the expense of the above-ground portion (stem and leaves). As a result, a carrot canopy can only achieve a very scanty ground cover[4]. Furthermore, since this crop completes its cycle during the spring–summer period, it is severely affected by competition from warm-season weeds. Greenhouse trials carried out to test the competitive ability of carrot against *Chenopodium album* L. (one of the typical weeds infesting carrot crops in Italy and elsewhere) showed that in comparison to carrot, the weed adapts more successfully to variations in environmental conditions, in particular plant density and available nutrients[5].

In order to provide the sensitive carrot crop with an initial competitive advantage, researchers have focused attention on preventive control strategies. For example, a three-year rotation of carrot–barley–onion allowed an appreciable reduction in weed density as compared to carrot monoculture, thereby also giving a better yield and more satisfactory product quality, due also to the decrease in population of the nematode *Meloidogyne hapla* Chitwood[6].

Experiments with soil disinfection have shown that this technique not only has a containing effect on the population of soil-borne pathogens, but it can *per se* constitute a means of preventive weed control. Soil solarization (i.e., prolonged solar heating of plastic mulch-covered soil during the warmest season) carried out prior to the sowing of carrot or string bean (*Phaseolus vulgaris* L.) can increase yield by reducing *Cyperus rotundus* L. emergence[7]. Steam soil disinfection also offers a possible solution for weed control in vegetable crops that have very slow germination and early growth[3,8–9]. Many such crops, including carrot, have notably heat-tolerant seeds, so that sowing and treatment operations could be performed at the same time[10].

However, because of the poor competitive ability of carrot, post-emergence treatments are considered crucial in order to ensure effective weed control in this crop. Carrot growers in the Fucino plateau have traditionally based weed control on herbicide application. This approach contrasts with the need to enhance product quality, as consumers today are increasingly aware of environmental and health-related issues and demand that food quality should not be limited to aesthetic and nutritional values, but should also concern the safety and wholesomeness of the product itself.

One of the main technical constraints to organic carrot growing is the very limited range of truly effective alternative direct weed control means capable of replacing chemical herbicides. However recent research has drawn attention to some equipment that could possibly be used successfully for non-chemical weed control in carrot. Several studies performed in Sweden tested a rotary brush on a vertical axis for intra-row weeding[4,11–14]. This machine achieved good results as the treatment proved to be very selective (with percent weed infestation reduced by 35–80%, depending on weed growth stage). In the Swedish studies, direct control was also integrated with a preventive strategy consisting of night-time soil tillage (giving weed reduction percentages ranging between 14 and 25%). Other research conducted in Hungary focused on a comparison among various weed control systems using a number of different treatment combinations. The effectiveness of the brush weeder was confirmed, but it was also pointed out that hand weeding is indispensable in a carrot crop for intra-row weed control[15,16].

A possible future evolution of non-chemical control could consist in the development of an automated system capable of distinguishing the crop from the weeds. Trials of this type have been performed at the University of Aberdeen (UK), where a special method of digital image analysis has been developed. Results showed that this form of artificial intelligence was able to discriminate (with up to 75% efficacy) carrot plants from those of two weed species: *Lolium perenne* L. and *C. album*[17].

Overall, it is clear that a successful weed control strategy must include preventive, cultural and also direct methods[18,19]. In particular, such a strategy should seek to improve intra-row weed control—which is at present the main limitation of direct mechanical means—in order to reduce the number of hours required for hand weeding. Trials on sugar beet in Denmark demonstrated a considerable reduction in the number of man-hours required for hand weeding if mechanical operating machines with spring tines, capable of performing selective intra-row weed control, were utilized in combination with manual weeding. Thus in the Danish experiment, the number of labor hours per hectare was reduced from 150 to less than 10[20]. When planning an integrated weed control strategy in organic carrot, local conditions such as farm structure and size, availability of equipment, traditional agricultural techniques, propensity of farmers to innovation and risk, and so forth, should also be taken into consideration.

In this framework, with the cooperation and funding of ARSSA Abruzzo (the regional agricultural extension service), since 2000 we have been engaged in a project to develop several operating machines, either purposely designed or modified from existing machinery, with the aim of proposing an improved weed control strategy in organic carrot. We thus developed an alternative crop management system specifically designed for the conditions of organic vegetable growers in the Fucino plateau.

Table 1. Mean soil characteristics in the experimental farms.

Characteristics	Value (%)
Sand	27
Silt	61
Clay	12
Organic matter	5

Materials and Methods

Trials involving physical weed control in an organic carrot crop were conducted over 4 years, from 2000 to 2003, on two organic farms located in the municipality of Avezzano (Province of L'Aquila, Region Abruzzo). In the first year, a conventional cropping system was compared with an organic system, but the same sowing typology (band sowing) was adopted in both cases. In the remaining years, the comparison was performed on organic cropping systems with different sowing typologies. More specifically, the comparison was performed between the standard system used on organic farms in the area (henceforth denoted as the 'standard' system), with band sowing, and an innovative organic system in which the crop was spatially arranged in single rows. In addition, in 2001 and 2002, a farm where early sowing had been carried out was compared with a late-sowing farm, while in 2003 the experiment was performed only on the early sowing farms, hence conducting a comparison between the two different organic systems both involving early sowing.

All farms adopted a vegetable crop sequence extending over a number of years, planting the typical vegetable crops of the area such as potato, chicory and fennel as well as carrot. The same tillage operations and fertilizer treatments were adopted in all the trials: application of manure (50–100 $m^3 ha^{-1}$ dairy manure), followed by plowing or deep tillage (at *c.* 40 cm depth) at the beginning of autumn, and numerous soil and seedbed preparation operations (grubbing, rotary hoeing and PTO-powered rotary harrowing). In the study area, soils are silty and have uniform properties, average values of which are shown in Table 1.

The crop was sprinkle irrigated with the use of a mobile unit composed of aluminum pipes to which the nozzles were fixed; the unit was connected to a motor pump powered by a fixed point tractor, which drew water from a purposely drilled well.

The trials included a comparison between two different sowing typologies: the standard system with five bands $coppa^{-1}$, the bands being 7 cm wide and spaced 30 cm apart, and an innovative typology with ten rows $coppa^{-1}$, the rows being spaced 18 cm apart. The *coppa* represents the traditional unit of surface measurement in the area, equal to a strip of land 2 m wide and 250 m long. Both typologies formed part of the same organic farming system. The ten-row spatial arrangement allowed the use of the innovative precision hoeing machine, while a conventional hoeing machine was adopted in the standard system. A randomized block design with four replications was adopted, each plot measuring 100 m^2 (2×50 m).

The initial sowing density for both typologies was 2,500,000 seeds ha^{-1}. Sowing was generally carried out within the third week of April, but in 2001 and 2002 a late sowing, i.e., at the end of May, was also performed. Two different F_1 carrot hybrids were utilized: 'Nandor' in the first 3 years and 'Maestro' in 2003. The latter is an earlier hybrid with a more developed leaf structure, which facilitates mechanical harvesting.

Harvesting was carried out mechanically with specially designed self-propelled equipment operating on a single row.

Total seasonal (April–September) rainfall and temperature followed the average of the area during 2001 and 2002 (27.2 versus 33.2 mm rainfall and 7.9/9.1 versus 24.4/23.4°C min/max temperature respectively), while 2003 was particularly warm and dry (11.9 mm rainfall and 9.6/26.5 min/max temperature) (Fig. 1).

Weed management systems and operating machines

Weed management in organic carrot required a complex strategy that was refined and improved from year to year, building on the experience gradually acquired. Improvements were likewise made on the operating machines. During the first year, tests were performed to assess the feasibility of physical weed control, identifying the suitable machines and their manner of utilization; thereafter (2001–2003), weed management was carried out with a system that included, in sequence, the following techniques (Fig. 2): (1) false seedbed with a spring-tine harrow, (2) pre-emergence flame weeding, (3) precision hoeing, (4) hand weeding. Flame weeding was used as the last pre-emergence treatment to avoid further soil disturbance which could have led to weed emergence flushes early in the carrot growing season, thereby partially counteracting the positive effect of the false seedbed technique. Intra-row hand weeding was performed to complement hoeing either before or after the mechanical treatment, and it was generally carried out when weeds had reached the four true leaves stage.

Some exceptions to the above-mentioned four-step strategy were occasionally introduced. For example, in the late sowing standard system in 2002 the spring-tine harrow was replaced by a PTO-powered rotary harrow, as the owner of the farm considered the latter implement to be more suitable for false-seedbed operations in his soil type. In 2003 two passes were made with the spring-tine harrow rather than just one, as the first pass was not sufficiently effective in stimulating weed emergence.

All the pieces of equipment were purposely designed for carrot growing in the Fucino area, and had a working width of 2 m, corresponding to that of the '*coppa*'. All physical weed control treatments were carried out by coupling the operating machines to a 2WD 48 kW tractor with a 2.1 m

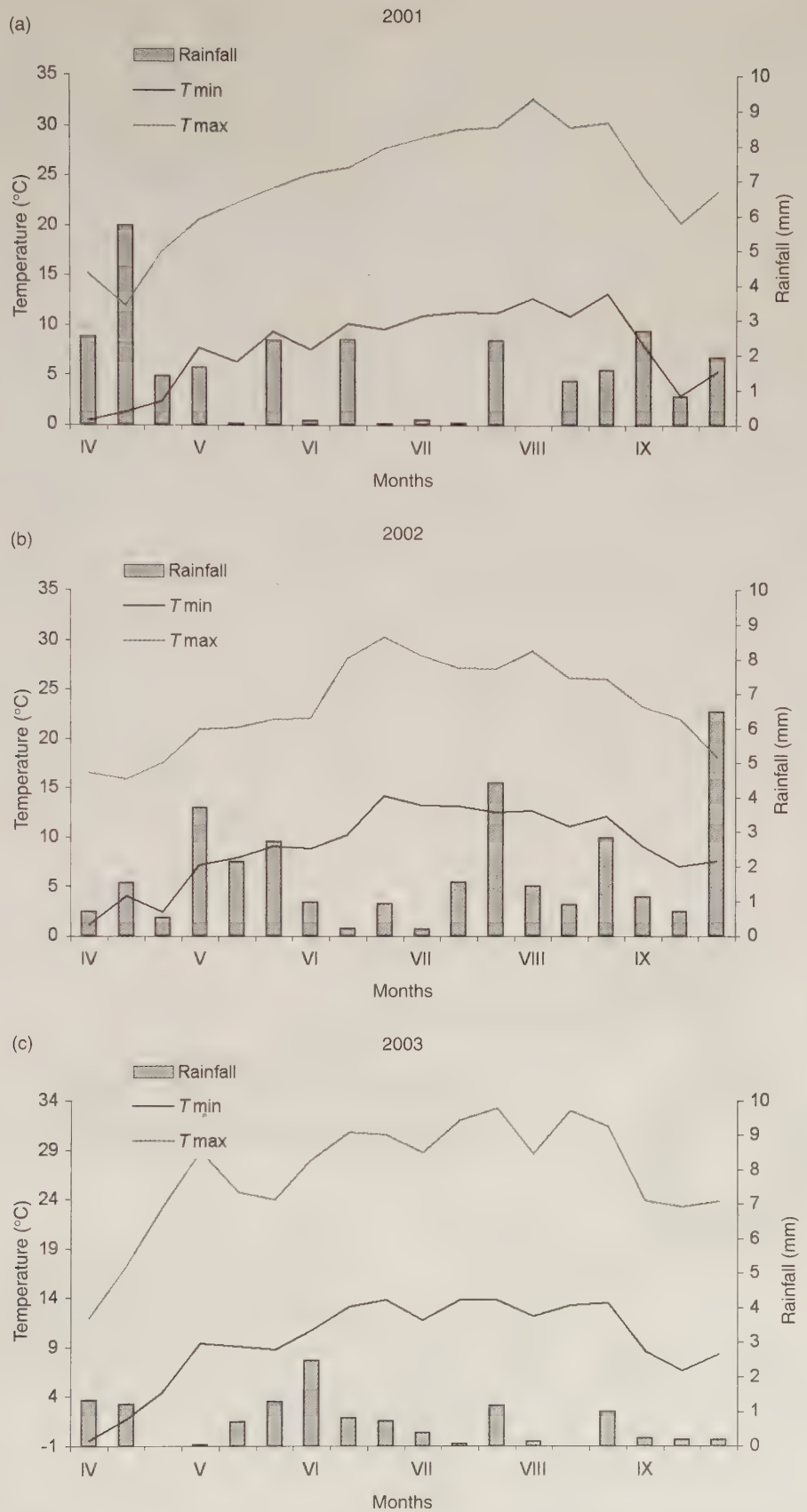

Figure 1. Mean decadic minimum and maximum temperature (*T*min and *T*max) and total decadic rainfall registered during the 2001 (top panel), 2002 (middle panel) and 2003 (bottom panel) growing season in the Fucino plateau (data from ARSSA Meteorological Center of Scerni).

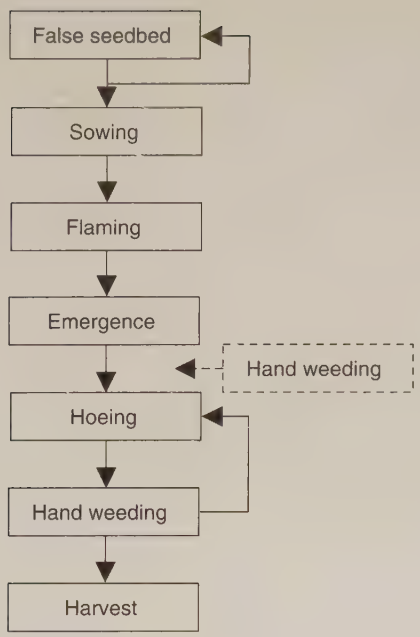

Figure 2. Scheme of the physical weed management strategy adopted on organic carrot in the Fucino plateau.

track gauge, making it possible to work by 'straddling' the strip.

The spring-tine harrow (Fig. 3) is the operating machine that was utilized for the false seedbed technique. Shallow soil tillage performed by this machine eliminates weeds already emerged in the field and at the same time stimulates the emergence of new weeds that will subsequently be eliminated by flame weeding before crop emergence. This method is designed to gradually reduce the soil seedbank population, with the aim of decreasing weed emergence during the crop growing cycle. The spring-tine harrow is a semi-mounted operating machine with the same working width as the above-described strip. It consists of two frames having identical working width (main and secondary, elastically connected by chains inserted in special U-shaped supports) bearing the working tools: six lines of 6 mm diameter J-shaped special steel spring-tines. The spring-tines are made up of two parts: a 25 cm long vertical segment and a second shorter, 11 cm long segment (sloping at an angle of 135° with respect to the vertical segment)[21–23]. This machine is regulated by a lever that can modify the slope of the tines and consequently the aggressiveness of treatment (negative angle values = least aggressive, positive angle values = more aggressive). In this trial the spring-tine harrow was set to the most aggressive regulation[24] and was used for non-selective pre-sowing treatment, at a driving speed between 4 and 8 km h^{-1}.

After false seedbed operations and prior to crop emergence, a pass with a flame weeder was carried out over the entire area. This operating machine kills weeds by using an open flame (fueled by Liquefied Petroleum Gas, LPG) that disrupts plant cells consequent to a strong and sudden increase in temperature. This treatment has the

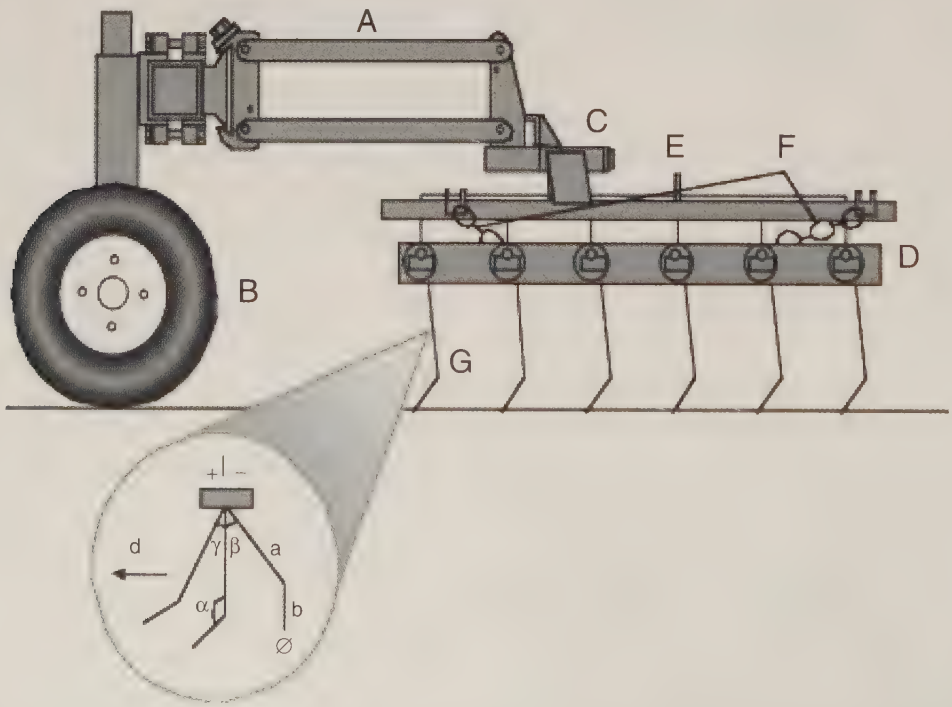

Figure 3. Diagram of the spring-tine harrow: (A) main frame; (B) supporting wheel; (C) U-shaped support; (D) modular secondary frame; (E) tine slope regulation lever; (F) chains; (G) spring-tines. Detail: (d) working direction; (a) = 25 cm (b) = 11 cm; Ø = 6 mm; $\alpha = 135°$; $\beta = 45°$; $\gamma = 15°$.

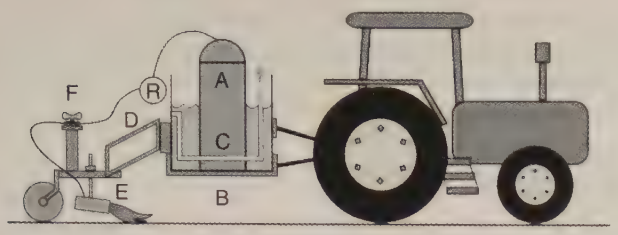

Figure 4. Illustration of the flamer: (A) LPG tank; (B) water-containing hopper; (C) heat exchanger; (D) articulated parallelogram; (E) burner; (F) shelf on which the inflow LPG control system is located; (R) pressure regulator and manometer.

advantage of eliminating weeds without stimulating new emergence because the soil remains undisturbed. The flamer was equipped with four 50 cm wide rod burners, for a total working width of 2 m (Fig. 4)[21–23]. The burners were set at 10 cm from the soil and at a 45° slope, based on previous experimental evidence[25,26]. Mean working speed was about 3 km h^{-1} with LPG pressure from 0.2 to 0.3 MPa.

An 11-element precision hoe (Figs. 5 and 6) was utilized several times during each year of the trial for post-emergence inter- and intra-row weed control[21–23] in the innovative, single row system. This machine, in the final optimized version used in 2002 and 2003, was equipped with rigid elements bearing a 9 cm wide horizontal blade (replacing the goose-foot push rod characterizing the first version), pairs of concave discs, and two alternative kinds of elastic tines (torsion weeders and vibrating tines, not used in 2001) designed to perform selective weed control in the crop row. The vibrating tines, which work in vertical position, have their longer segment bent at several points in order to till very close to the crop row. The torsion weeders, on the other hand, work in horizontal position; a torsion spring enables the tines to flex when they meet a fairly developed plant (generally a crop plant but it could also be a large weed) that opposes resistance to the implement. The position of both tools can be modified according to the treatment aggressiveness required. Treatment becomes more intense when the tines are positioned close to the row crop[20]. The working speed of the hoe was *c.* 2 km h^{-1}.

A back-seated operator can adjust the actual position of the working tools by operating a steering handle. The hand guidance system might be replaced in the future by less labor-demanding guidance systems based upon electronic, optical or hydraulic applications, allowing to perform precision hoeing without the need of a back-seated operator.

Experimental assessments

During the trials, four different types of assessments were performed, on: (a) machine operative characteristics, (b) weeds, (c) crop yield and yield quality, and (d) crop economy.

Machine operative characteristics. During the trials, all data concerning the operative performance of the weed management systems and machinery used for physical weed control were recorded: working depth, working speed (this value being used, together with working width, for calculation of operative capacity and operating time), engine load, LPG working pressure, fuel and LPG consumption.

Weeds. Numerous weed parameters were recorded at repeated intervals. Weed density was measured before and after each physical weed control treatments on three 25×30 cm sampling areas $plot^{-1}$. At harvest, weed samples were collected from a 2 m^2 area $plot^{-1}$. Samples were then oven dried until constant weight, in order to assess dry biomass of weeds.

Crop yield and yield quality. For measurement of crop production parameters, the density of carrot plants was measured before and after each treatment (along 50 cm of row in each of 5 samples $plot^{-1}$). In addition, at harvest, measurements were performed on a 2 m^2 area $plot^{-1}$ to evaluate overall root production (weight and number) and the relative percentage distribution of roots in each marketable produce class (extra, first category, second category, ungraded), as required by EU Regulation no. 730 of 1999[27].

Crop economy. In each trial year, crop gross margin (not including land costs) was calculated by subtracting

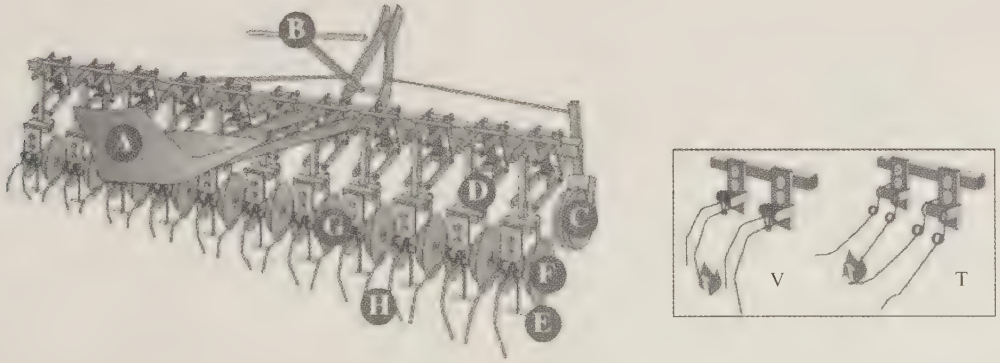

Figure 5. Illustration of the 2002 version of the precision hoe: (A) seat; (B) steering handle; (C) directional wheel; (D) articulated parallelogram; (E) tine with blade tool; (F) side discs; (G) support wheel; (H) tools for intra-row weeding (in the right-hand side picture, vibrating tines (V) and torsion weeders (T) are shown in detail).

Figure 6. Precision hoe (equipped with vibrating teeth) at work, performing early post-emergence treatment in organic carrot in 2002.

costs from gross salable production. Costs were defined as tillage and seedbed preparation costs (plowing, grubbing, rotary hoeing, PTO-powered rotary harrowing), cost of fertilizer (manure and spreading operations), sowing (purchase of raw material and sowing operations), weed management (treatment with the operating machines for physical weed control as well as cost of labor for hand weeding), and mechanical harvesting. The mean market price of organic carrot in the Fucino plateau for each trial year and each class of marketable produce[27] was communicated by ARSSA Abruzzo. Estimate of the costs of cultural practices (except that of physical weed control) were based on the price lists of local work contractors. Costs for utilization of the equipment needed for physical weed control were calculated by means of standard procedures for calculation of operating costs[28,29]. Labor costs were $10\,€\,h^{-1}$.

Statistical analysis. Analysis of variance (ANOVA) was carried out on each measured parameter (except operative characteristics of the machines) according to a randomized complete block design with four replicates. Treatment means were compared by a protected LSD test at $P \leqslant 0.05$.

Results

Machine operative characteristics

Technical data collected on machine operative characteristics in 2001, 2002 and 2003 are shown in Table 2.

The working depth of the spring-tine harrow during the 3-year period varied between 3 and 4 cm. A greater working depth was achieved in 2002, consequent to use of a more aggressive tine adjustment. Working speed varied as a function of soil conditions, and was higher in optimum moisture conditions. Thus speed was elevated in 2001 ($7.6\,km\,h^{-1}$) and more restrained in 2002 ($4.6\,km\,h^{-1}$), while in 2003 one pass was performed at moderate speed (*c.* $4\,km\,h^{-1}$) and a second at higher speed (*c.* $8\,km\,h^{-1}$).

Flame weeder speed and working capacity showed no significant variation during the trial years. Working pressure of LPG was more contained in 2001 (0.2 MPa) as compared to the subsequent 2 years (0.3 MPa). This increase in pressure accounts for the higher LPG consumption (+45% on average) during the last 2 years, given that working speed remained substantially unchanged over the 3-year period. It should be noted that LPG consumption is correlated with the two above cited factors: positively with working pressure and negatively with working speed. Greater working pressure was required when more strongly developed weeds were encountered. LPG is liquid in the tanks placed in the hopper, but it naturally evaporates and it is then used as a gas to the burners. This passage requires heating the tanks by a heat exchanger and it is the safest system that can be used in flaming machines.

Finally, the optimized version of the precision hoeing machine allowed an appreciable reduction (−52% on

Table 2. Operative characteristics of the machines used for physical weed control in organic carrot in the years 2001, 2002 and 2003.

		2001			2002			2003			
Characteristics		**Har**	**Fla**	**Hoe**	**Har**	**Fla**	**Hoe**	**Har 1**	**Har 2**	**Fla**	**Hoe**
Working width	(m)	2	2	2	2	2	2	2	2	2	2
Working depth	(cm)	3.3	–	4.9	4.1	–	2.9	2.8	3.2	–	1.8
Working speed	($km\,h^{-1}$)	7.6	3.0	2.3	4.6	2.4	1.8	3.9	7.8	3.0	2.2
Working capacity	($ha\,h^{-1}$)	1.3	0.6	0.4	0.8	0.4	0.3	0.7	1.4	0.5	0.4
Working time	($h\,ha^{-1}$)	0.8	1.7	2.6	1.1	2.3	3.1	1.4	0.7	1.9	2.6
Operators	(No.)	1	1	2	1	1	2	1	1	1	2
Tractor engine capacity	(kW)	48	48	48	48	48	48	48	48	48	48
Engine load	(%)	20	20	40	20	20	40	40	40	40	40
Fuel consumption	($kg\,ha^{-1}$)	2.0	4.3	13.5	2.7	5.8	15.4	7.5	3.0	9.6	13.5
LPG pressure	(MPa)	–	0.2	–	–	0.3	–	–	–	0.3	–
LPG consumption	($kg\,ha^{-1}$)	–	40.0	–	–	64.0	–	–	–	52.0	–

Har = harrowing (1, 2 = first or second pass), Fla = flame weeding; Hoe = hoeing.
Data refer to innovative system.

Table 3. Labor time required for physical weed control in carrot grown with the two management systems on two organic farms of the Fucino plateau in the period 2001–2003. In each column and year, means labeled with different letters are significantly different at $P \leq 0.05$ (LSD test); ns = not significant.

		Labor time ($h\,ha^{-1}$)	
Year	Management system	Early sowing farm	Late sowing farm
2001	Standard	215 a	201 a
	Innovative	135 b	131 b
2002	Standard	168 ns	91 a
	Innovative	166 ns	54 b
2003	Standard	658 a	–
	Innovative	476 b	–

average) in working depth as compared to 2001. Working speed, on the other hand, underwent no marked variation during the 3-year trial period; consequently, working capacity and fuel consumption remained virtually unchanged. In 2003, in the innovative system a third pass of precision hoeing was performed, due to the elevated weed density which may have been due to the presence of viable seeds in insufficiently mature manure.

Total labor employed over the trial years varied considerably. As shown in Table 3, a greater quantity of labor was required in 2003, as unsuccessful false seedbed operations resulted in high weed density during the crop cycle, leading to a greater requirement of hand weeding. However, the innovative system consistently allowed a notable savings on labor time (on average, −28% during the 3-year period). In 2002 the difference between the two systems in terms of the number of labor hours required for hand weeding was virtually nil for the early sowing farm (Farm 1: 168 and 166 $h\,ha^{-1}$ for the standard and the innovative systems respectively). In contrast, on the late sowing farm (Farm 2) labor time was on average 40% lower in the innovative system than in the standard system (91 versus 54 $h\,ha^{-1}$) (Table 3). This was mainly due to the fact that on Farm 2, hand weeding was performed prior to hoeing in order to remove the larger weeds and maximize the efficacy of hoeing operations. This strategy was not adopted on Farm 1, where the presence of weeds in an advanced stage of development noticeably reduced the effectiveness of the operation. In addition, in the standard system of Farm 2, the false seedbed technique was performed by means of a rotary harrow (instead of the spring-tine harrow), which caused pronounced soil disturbance, thereby creating the ideal conditions for prolonged weed emergence throughout the growing cycle, which increased the difference between the two weed management systems. In the innovative system, pre-hoeing hand weeding was also adopted in 2003 for the second and third hoeing passes, allowing a considerable reduction in total hours needed for hand weeding as compared to standard system (−77% on average).

The percentage of labor time needed for mechanical operations out of total working hours was fairly limited in the 2001–2003 3-year period, as almost all labor was associated with hand weeding. This percentage varied considerably (from 3% to *c.* 12%) depending on the year and the strategy adopted, and was generally higher in the innovative system and in years characterized by lower weed competition (2001–2002).

The marked difference in labor required for hand weeding in the various trial years is attributable to different weed emergence patterns from year to year. In particular, the final trial year was characterized by massive weed growth after crop emergence.

Weeds

In 2001, weeds consisted mainly of *Amaranthus* spp. L. and *C. album*, which together accounted for 90–95% of the overall weed community. Among other weeds, only *Echinochloa crus-galli* (L.) P. Beauv. achieved a noteworthy density.

In contrast, in 2002 the weed community was more differentiated and complex. On the early sowing farm, initially the main weeds were: *C. album*, accounting for 48% of relative density, some crucifers (*Diplotaxis erucoides* (L.) D.C., and *Sinapis arvensis* L.) accounting for 38% and *Amaranthus* spp. accounting for 7%. Subsequently, other weeds became dominant, such as *Polygonum aviculare* L. (up to a maximum relative density of 29%) or *Mercurialis annua* L. (up to 27%). On the late sowing farm, crucifers (especially *D. erucoides*) initially had the highest density (34%), closely followed by *Polygonum lapathifolium* L. (16%), *C. album* (12%) and *Cuscuta campestris* Yuncker (11%). During the carrot growing cycle, the weed community composition shifted in favor of crucifers, which at some point achieved a relative density >80%.

In 2003, the main weeds present initially consisted of two Chenopodiaceae (*C. album* and *Atriplex latifolia* Wahlenb.) plus *D. erucoides* (77 and 10% of relative density respectively). Subsequently, perhaps as a result of a rise in temperature, considerable populations of *P. lapathifolium* and *Amaranthus* spp. were also recorded. During the growing cycle, Chenopodiaceae, together with *Amaranthus* spp. and *P. lapathifolium*, were the most widespread weeds, often representing almost the totality of weeds present in the field.

The highest initial absolute density of weeds was recorded in 2001 (233 weeds m^{-2} on Farm 1 and 184 weeds m^{-2} on Farm 2). By harvest time, however, use of mechanical weed control and hand weeding allowed a 96% reduction in weed density on Farm 1 and 97% on Farm 2.

In 2002, on the early sowing farm (Fig. 7a) mean initial weed density (100 weeds m^{-2}) was lower than in the

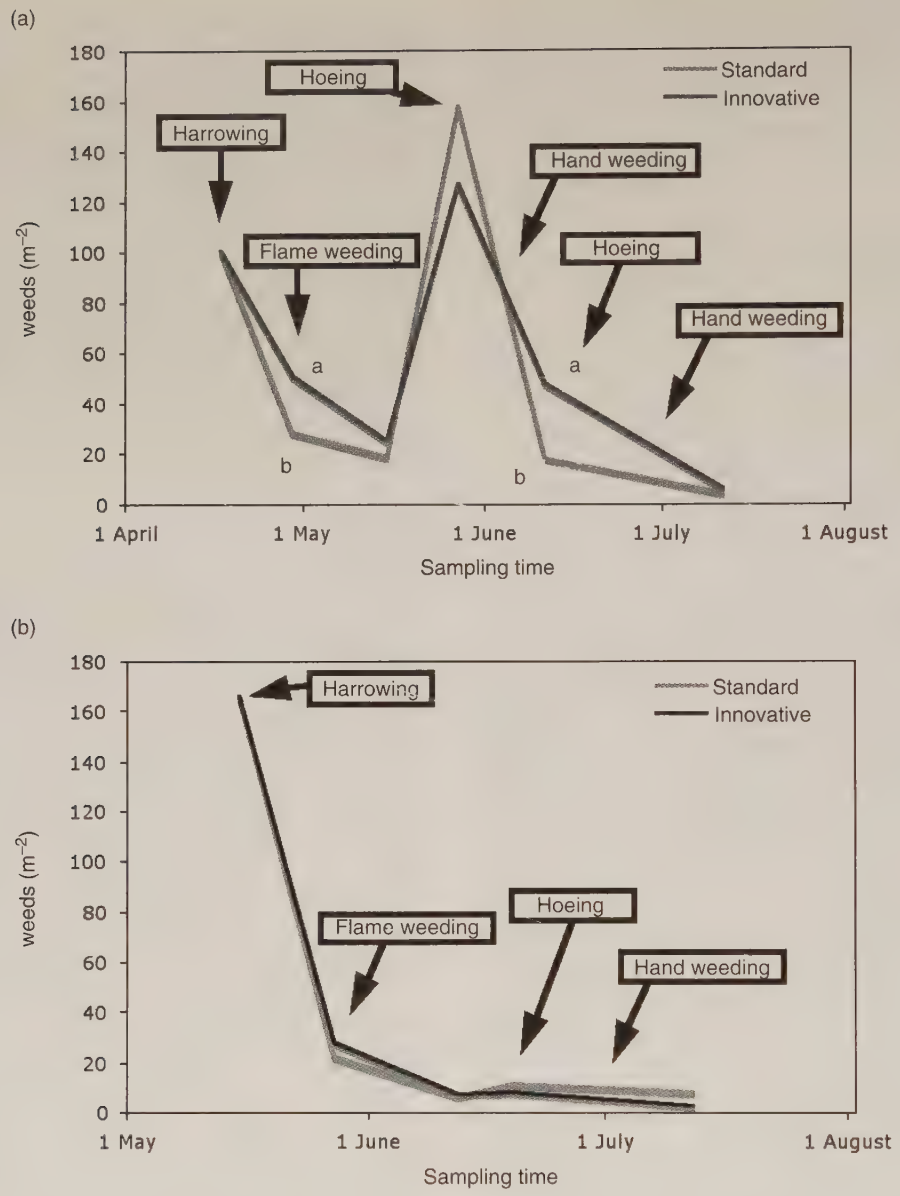

Figure 7. Pattern of weed development during the 2002 season in organic carrot grown according to the standard and innovative management systems, on the early sowing (a) and late-sowing (b) farms. Different letters indicate significant differences for $P \leqslant 0.05$ (LSD test).

previous year (−57%). Preventive weed management operations (harrowing and flame weeding) substantially reduced total weed density both in the standard and the innovative system (respectively −81 and −75%), but densities then rose to higher than initial values (+57% in the standard and +27% in the innovative system) as a result of massive weed emergence occurring prior to the first hoeing operation. However, the two hoeing operations almost completely eliminated weeds (−96 and −94% of total initial densities in the standard and innovative system respectively). It should be noted that the first precision hoeing pass in the 10-row system was not very effective (62% reduction), mainly due to the presence of very large weeds.

In 2002, initial weed density was 66% higher on the late sowing farm (166 weeds m^{-2}) than on the early sowing farm, but the two preventive weed management treatments reduced weed presence by 96% in both systems (Fig. 7b). In addition, lower levels of subsequent weed emergence were recorded after flame weeding, and precision hoeing achieved greater efficacy in the 10-row innovative system (75% weed control) thanks to prior hand weeding. Taken together, these operations gave final results similar to those of the early sowing farm, but with decidedly fewer (−57%) labor hours (Table 3).

In 2003 (Fig. 8), because of a particularly cold and dry spring, initial weed density was very low (only 35 weeds m^{-2}). The first pass with the spring-tine harrow

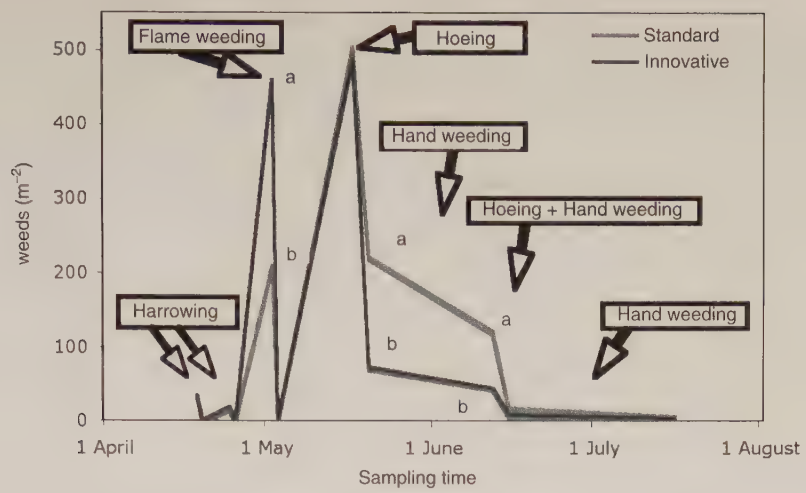

Figure 8. Pattern of weed development during the 2003 season in organic carrot grown according to the standard and innovative management systems in the early sowing farm. Different letters indicate significant differences for $P \leqslant 0.05$ (LSD test).

reduced weed density by roughly 97%, but it did not stimulate the emergence of new weeds. Thus after 6 days, a mean value of only 19 weeds m^{-2} was recorded. Due to the failure of the first preventive operation, a second pass with the spring-tine harrow was performed. Weed density was again reduced to virtually nil. However, massive weed emergence occurred after crop sowing, partly due to the stimulus inherent in sowing operations and partly to a temperature rise. Weed density was particularly high in the innovative system (+119% as compared to the standard system). This was probably attributable to the greater volume of soil disturbed by the 10-row seeder compared to the 5-band seeder. However, this effect should not necessarily be regarded as negative, since flame weeding prior to crop emergence once again reduced weed density to virtually nil. Even so, substantial weed emergence recurred, and the mean weed density by the time of the first hoeing was roughly 500 weeds m^{-2}. In the innovative system, precision hoeing, which achieved 85% efficacy, restored weed density to acceptable levels, while in the standard system hoeing achieved no more than 56% reduction. This difference was likely due to the fact that the 10-row spatial arrangement, composed of individual rows, allowed more successful intra-row weed control. Subsequently, weed density was gradually reduced as a result of additional hoeing and three hand-weeding operations. It should be pointed out that in the innovative system the number of weeds remained significantly lower until the end of the crop cycle. This allowed a notable savings (28%) on labor time as compared to the 5-band, standard sowing system.

No significant differences were observed in the total percent reduction of intra-row weeds in 2002 and 2003 in the innovative system when comparing use of the torsion weeder with that of vibrating tines (data not shown). Intra-row weed reduction was on average 72% in 2002 and 78% in 2003 (this kind of intervention is mostly effective when performed on seedlings).

Crop yield and yield quality

In 2001 no significant differences between the two physical weed management systems were recorded on either of the two farms, with the exception of extra category carrots on Farm 1, which were only produced with the standard system (Table 4). Total production was decidedly lower for late sowing (−25%) as compared to early sowing, but the latter was associated with a smaller root mass in the extra category (−66%).

In the years 2002 and 2003 carrot showed the same production trend. The innovative system had a higher mean density of carrot plants (+28% on Farm 1 both in 2002 and 2003; +55% on Farm 2 in 2002) and a higher root yield (+30% on Farm 1 in 2002 and 2003; +42% on Farm 2 in 2002). In 2002, late sowing again gave a lower carrot yield (−37%) compared to early sowing (Table 5). In 2003 (in which only early sowing was taken into account), carrot yield was somewhat lower compared to the previous year, due to drought which affected the crop throughout the entire cycle (Fig. 1). The higher yield of the innovative system in the 2-year period 2002–2003 was mainly attributable to higher 2nd category root yield, and, only for 2003, also to higher extra carrot root yield (Table 6). The higher yields recorded in the two-year period 2002–2003 in the innovative system may be ascribed to the increased effectiveness of precision hoeing, which allowed better intra-row weed control through the use of spring-tines.

Crop economy

As shown in Table 7, actual physical weed control costs varied considerably upon year, farm and management system. However, in all but one case, use of the innovative system resulted in significantly lower costs, ranging from 121 to 1153 € ha^{-1} (average: 416 € ha^{-1}). In 2003, because of the massive weed growth that occurred mainly after crop

Table 4. Yield parameters and biomass and percent distribution of roots among commercial quality categories in organic carrot grown with the standard and innovative management systems in the early and late-sowing farms in 2001. For the same line and character, means labeled with different letters are significantly different at $P \leqslant 0.05$ (LSD test), ns = not significant.

	Early sowing (Farm 1)				Late sowing (Farm 2)			
Yield parameters	**Standard**	**Innovative**	**Standard**	**Innovative**	**Standard**	**Innovative**	**Standard**	**Innovative**
Density (plants m^{-2})	135 ns	129 ns			129 ns	132 ns		
Yield (f.m.) ($t\,ha^{-1}$)	77.5 ns	75.9 ns			57.4 ns	58.1 ns		
Quality category	**($t\,ha^{-1}$)**		**(%)**		**($t\,ha^{-1}$)**		**(%)**	
Extra	2.1 a	0.0 b	2.7 a	0.0 b	2.0 ns	3.9 ns	3.5 ns	6.7 ns
1st	26.6 ns	27.5 ns	34.3 ns	36.2 ns	6.7 ns	6.3 ns	11.7 ns	10.8 ns
2nd	35.5 ns	35.7 ns	45.8 ns	47.0 ns	34.7 ns	32.1 ns	60.5 ns	55.2 ns
Hors	13.3 ns	12.7 ns	17.2 ns	16.7 ns	14.0 ns	15.8 ns	24.4 ns	27.2 ns

f.m. = fresh matter.

Table 5. Yield parameters and biomass and percent distribution of roots among quality commercial categories in organic carrot grown with the standard and innovative management systems in the early and late-sowing farms in 2002. For the same line and character, means labeled with different letters are significantly different at $P \leqslant 0.05$ (LSD test), ns = not significant.

	Early sowing (Farm 1)				Late sowing (Farm 2)			
Yield parameters	**Standard**	**Innovative**	**Standard**	**Innovative**	**Standard**	**Innovative**	**Standard**	**Innovative**
Density (plants m^{-2})	140 b	179 a			81 b	126 a		
Yield (f.m.) ($t\,ha^{-1}$)	91.8 b	119 a			54.5 b	77.4 a		
Quality category	**($t\,ha^{-1}$)**		**(%)**		**($t\,ha^{-1}$)**		**(%)**	
Extra	3.0 ns	2.9 ns	3.3 ns	2.4 ns	0.0 ns	0.5 ns	0.0 ns	0.7 ns
1st	22.0 ns	25.3 ns	23.9 ns	21.2 ns	12.5 ns	9.0 ns	23.0 a	11.7 b
2nd	50.9 b	73.5 a	55.4 b	61.7 a	31.2 b	51.4 a	57.2 ns	66.4 ns
Hors	16.0 ns	17.6 ns	17.4 a	14.7 b	10.8 b	16.4 a	19.8 ns	21.2 ns

f.m. = fresh matter.

Table 6. Yield parameters and biomass and percent distribution of roots among commercial quality categories in organic carrot grown with the standard and innovative management systems in 2003 (early sowing farm). For the same line and character, means labeled with different letters are significantly different at $P \leqslant 0.05$ (LSD test), ns = not significant.

Yield parameters	**Standard**	**Innovative**	**Standard**	**Innovative**
Density (plants m^{-2})	139 b	178 a		
Yield (f.m.) ($t\ ha^{-1}$)	65.3 b	85.1 a		
Quality category	**($t\,ha^{-1}$)**		**(%)**	
Extra	0.0 b	3.1 a	0.0 b	3.7 a
1st	6.6 ns	14.1 ns	10.1 ns	16.6 ns
2nd	33.7 b	49.3 a	51.6 ns	57.9 ns
Hors	25.0 a	18.5 b	38.3 a	21.7 b

f.m. = fresh matter.

sowing, a large quantity of labor was required for hand weeding. As a result, costs escalated in comparison to the previous years. Despite this, the innovative system still allowed a savings of *c.* 1000 € ha^{-1}. Furthermore, the 10-row innovative system also allowed significant savings in 2001 (roughly 500 € ha^{-1}), and on the late-sowing farm in 2002 (roughly 250 € ha^{-1}), while on the early sowing farm the estimated cost was virtually the same for both systems.

The estimated gross margin is in accordance with the yield data obtained for the two management systems (Table 8). In 2001 no significant differences between the two systems were recorded, while in the two subsequent

Table 7. Physical weed control costs in carrot grown with the standard and innovative system on two organic farms in the Fucino plateau in the period 2001–2003. For the same farm and year, values labeled with different letters are significantly different at $P \leqslant 0.05$ (LSD test).

		Physical weed control costs (€ ha^{-1})	
Year	Management system	Early sowing farm	Late sowing farm
2001	Standard	1522 a	1435 a
	Innovative	1026 b	1001 b
2002	Standard	1243 ns	741 a
	Innovative	1230 ns	511 b
2003	Standard	4115 a	–
	Innovative	2962 b	–

Table 8. Estimate of gross margin obtained from organic carrot in two farms in the 2001–2003 period. For the same farm and year, values labeled with different letters are significantly different at $P \leqslant 0.05$ (LSD test).

		Gross margin (€ ha^{-1})	
Year	Management system	Early sowing farm	Late sowing farm
2001	Standard	29,303 ns	18,275 ns
	Innovative	29,134 ns	18,952 ns
2002	Standard	28,566 b	15,154 b
	Innovative	38,521 a	22,481 a
2003	Standard	11,280 b	–
	Innovative	23,414 a	–

years the innovative system, which achieved more effective weed control and higher yields, gave an appreciably higher gross margin (on average *c.* +40% in 2002 and *c.* +100% in 2003), ranging from 22,481 to 38,521 € ha^{-1}.

Discussion

The data obtained in this research demonstrate that an appropriate physical weed management strategy can effectively reduce weed density, limit the hours of labor required for hand weeding and at the same time guarantee very satisfactory production, in terms of yield, quality and gross margin. However, these results could not have been obtained if direct post-emergence intervention had been the only means adopted. For example, false seedbed plus flaming (stale seedbed technique) proved to be the key operation of the entire strategy, being essential for the successful outcome of the subsequent weed control operations. The crucial importance of the stale seedbed technique is clearly shown by many of the data recorded in the 3-year period, but it is strikingly synthesized by the higher labor requirement needed for hand-weeding in 2003, i.e., the year in which the false seedbed technique was rather ineffective. This failure was mainly attributable to an adverse weather pattern: a dry and rather cold spring delayed peak weed emergence, so that maximum weed seedling density was recorded after crop emergence (in parallel with an increase in average air temperature). Such conditions were extremely unfavorable for the subsequent hoeing operations. In 2001 and 2002, on the other hand, the false seedbed technique very well stimulated weed emergence (from 100 to >200 weeds m^{-2}), and the efficiency of the operating machines, which was consistently higher (from 46 to 87%), succeeded in achieving a marked reduction in weed density. This demonstrates that application of preventive weed management methods is of utmost importance in the case of poorly competitive crops[18].

In several studies which included the use of different preventive methods, variable results were likewise obtained. Fogelberg[13] utilized night-time soil cultivation on carrot, reducing weed emergence from 15 to 25%, but this control percentage was enhanced by means of post-emergence brush weeding. Melander[30] adopted the same combination of operations on onion (*Allium cepa* L.) and kale (*Brassica oleracea* L. var. *acephala* DC. subvar. *laciniata* L.), obtaining up to 90% weed reduction in trials designed to reduce the labor requirements for intra-row hand weeding.

With regard to post-emergence treatments, it is important to note the high weeding effectiveness of the 11-tine precision hoe (which achieved up to 90% control). This implement allowed a marked labor saving in the innovative system as compared to the standard system. This saving was mainly due to the ability of this machine to work also along the crop row, thanks to its pair of spring tines. However, the effectiveness of precision hoeing was considerably improved by timely hand weeding performed immediately prior to the hoeing operation itself. Hand weeding eliminated larger weeds, which thus no longer interfered with the action of the spring-tines, as the selective weed removal along the row performed by the spring-tines is unable to eliminate adult weeds and can only uproot or cover weeds in the cotyledon or seedling stage. Intra-row weed reduction levels averaged 74% both for the torsion weeder and the vibrating spring-tines. Similar levels of intra-row weed reduction were obtained in Fogelberg and Kritz's trials[14], in which a brush weeder equipped with brushes rotating on a vertical axis achieved a mean control efficiency of 89%, this value being obtained on weeds at the stage of two true leaves. Weed control decreased to 35% when weeds were at the 6 to 8 true leaves stage.

It is worth noting that use of torsion weeders and vibrating tines was possible only with the adoption of the single-row crop spatial arrangement, which in the innovative system replaced the traditional band-sown crop.

Numerous studies have tested new crop spatial arrangements in order to facilitate the action of operating machines adopted for post-emergence physical weed control, for example on pigeon bean[31] (*Vicia faba* L. var. *minor*), vining pea[32] (*Pisum sativum* L.) and winter wheat[33] (*Triticum aestivum* L.), obtaining good weed reduction percentages with the aid of hoeing machines that could not otherwise be utilized. As such, crop spatial arrangement is to be considered one of the options available for 'cultural' weed management, which, alongside with preventive and direct methods, should always be represented in any weed management strategy set forth in organic agriculture[18].

At present, despite the effectiveness of innovative machinery, hand weeding operations can be reduced but not completely eliminated in organic vegetable cropping. The importance of hand weeding is also underlined in the multi-year trials on physical weed control in carrot undertaken by Radics[15] and Gàl[16]. On the other hand, it should not be overlooked that hand weeding may constitute a danger for the crop, as it may frequently result in inadvertently uprooting crop plants. In the standard crop spatial arrangement, carrots are sown randomly within the band, thus increasing the risk of accidental uprooting. This may explain why, at harvest, carrot plant density was on average higher in the innovative system, where precision single-row sowing facilitated identification of the crop.

Carrot showed good resistance to the use of torsion weeders and vibrating tines, confirming the excellent anchorage characteristics of this crop[4]. The slightly higher root commercial quality obtained with the innovative system is possibly attributable to the fact that the single rows, together with precision sowing, lead to a more rational arrangement of the space available to the crop, giving the tap root greater room for both downward and lateral growth[34]. In the past, the single row arrangement was the normal crop typology used by farmers in Fucino plateau, but the band system gradually became more widespread because it facilitated chemical weed control. Consequently, the single-row spatial arrangement of carrot is now considered by local farmers as a form of 'return to the past', and even producers who engage in organic farming generally prefer to maintain the band typology, which however is not suitable for physical weed control. Ongoing extension activities that we are conducting in collaboration with ARSSA Abruzzo would hopefully change this irrational attitude.

It is also important to underline that residues are generally incorporated in the soil by primary and secondary tillage, thus this kind of weed management system (after stale seedbed technique) is actually a 'clean tillage' system, but, at the same time, it is perfectly suitable to organic agriculture, and applicable to a large range of vegetables, both sown (e.g., spinach, *Spinacia oleracea* L.) and transplanted (e.g., chicory, *Cichorium intybus* L.; fennel, *Foeniculum vulgare* Mill.; tomato, *Lycopersicon esculentum* Mill.; and cabbage, *B. oleracea* L.).

Conclusions

Results of this study clearly demonstrate that organic carrot growing in the Fucino plateau can be successfully conducted, despite the crop being very sensitive to weed competition. In our trials, physical weed control operations, whose effectiveness was improved year after year through increasingly optimized techniques, consistently allowed good weed control. Use of the innovative organic system, in which carrot is sown in 10 single rows, resulted in the greatest effectiveness of mechanical treatments, as this management system allowed substantial intra-crop weed control as well. Furthermore, this system not only had lower overall costs (due to more limited use of labor for hand weeding), but it also achieved a higher root yield and consequently a higher crop gross margin. These results also show that there is not necessarily a correspondence between the complexity of measures that must be deployed in an effective organic weed management strategy (based on sound integration among preventive, cultural and direct methods) and the complexity and cost of technical solutions (tactics) included in such strategy. The best investment for organic farmers is always that on the knowledge (weed biology and ecology, crop/weed interactions, technical innovations) that they need to build up a strategy fine-tuned to their specific cropping situation. On the economic side, at present, considering the very high market value of organic carrots, use of the innovative weed management system can turn into an expected potential gross margin for the farmer of up to *c.* 40,000 € ha^{-1}. These motivations would certainly be sufficient to justify adoption of the innovative system, but this new management approach—for reasons related to tradition—is not yet favorably received by Abruzzi farmers. However, results of these trials are beginning to 'break through' farmers' resistance to innovation, which is rather common in the study area.

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Mining pesticide use data to identify best management practices

Emily Oakley[1,*], Minghua Zhang[1,2], and Paul Richard Miller[1,3]

[1]Department of Land, Air and Water Resources, University of California Davis, CA 95616, USA.
[2]California Department of Pesticide Regulation, Sacramento, CA 95814, USA.
[3]Department of Rural Engineering, Federal University of Santa Catarina, Brazil.
*Corresponding author: eaoakley@lycos.com

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Abstract

This paper reports on the initial findings of an ongoing research project to capture differences in pest management strategies and decision-making among growers using the California Pesticide Use Reports (PUR) database. Analysis was performed for prunes in Sutter and Yuba counties to identify on-farm innovation by analyzing the PUR for best management practices to reduce pesticide use. Results showed that large variations in pesticide use were present in 2000, with a range of less than 5 kg to more than 41 kg of pesticide applied per hectare (ha) crop planted in Sutter County and a range of less than 2 kg to close to 30 kg per ha crop planted in Yuba County. Among the 42 growers selected cultivating more than 80 ha, five growers in Sutter County and three growers in Yuba County in 2000 were identified as low pesticide use growers. The results indicated a surprising number of low to no fungicide users and an even higher number of growers using no herbicides in both counties. Twenty-nine viable low pesticide use growers were identified overall among the total 294 growers in the Sutter and Yuba counties. However, there were no spatial patterns of where these low pesticide use growers' fields were located. The transition from higher-risk active ingredients (AIs) to reduced-risk AIs used by many of the low pesticide users suggests intentional substitution. Initial yield data indicate that quantity and quality were not adversely affected by low use growers employing reduced-risk pesticides, fewer (AIs) per field, and lower rates per chemical than their moderate to high use counterparts. Diverse collaborators consisting of university researchers, environmental and community organizations, state government scientists, and growers worked together throughout the entire project, beginning with defining the research parameters, then interpreting the results, and finally suggesting practical applications for the outcomes. The paper also highlights the effectiveness of using such collaborative research relationships to explore low pesticide use alternatives, to directly exchange research findings with growers, and to encourage a farmer-to-farmer extension model.

Key words: active ingredient (AI), farmer-to-farmer, information cycling, low pesticide use, on-farm innovation, Pesticide Use Reports (PUR), reduced-risk

Introduction

California has a unique pesticide tracking program whose scope and detail is not matched anywhere else in the country or in the world[1]. This Pesticide Use Reports (PUR) database is administered by the California Department of Pesticide Regulation (DPR). All California farmers are required to fill out detailed reports about the pesticide products applied on their fields. Farmers send their reports to their agricultural commissioner's office where they are compiled into county-wide databases. At the end of the year, DPR aggregates the databases from all 58 California counties into a single, statewide system. Over 2.5 million records of chemical applications are collected annually. This has resulted in a rich and comprehensive database of pesticide use since the inception of the program in 1990[1].

This paper reports on the initial findings of an ongoing research project to capture differences in pest management strategies and decision-making among growers using the California PUR database. The project represents a unique use of the PUR—examining patterns of and trends towards low pesticide use among individual growers. The PUR database served as a tool to identify growers using innovative management practices to reduce pesticide use. The project is comprised of collaborative relationships between researchers and commodity and community organizations, connecting computer-generated research results with growers on the ground.

Variation in the amount of pesticide use can be observed among farmers when they grow the same commodity within a county, and these variations of use can be associated with agronomic, socio-economic, and environmental

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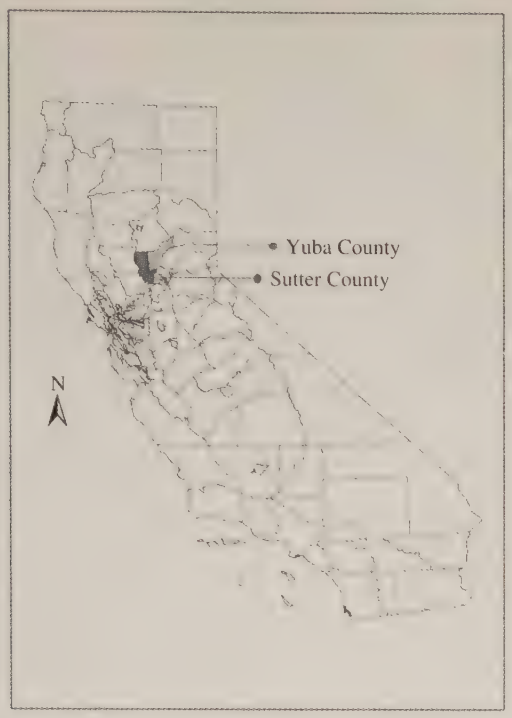

Figure 1. Study area, location of Sutter and Yuba counties in California.

and biological factors[2]. Differences in orchard age, yield histories and projections, and cost per hectare from one farm to another affect pesticide use. Socio-economic forces include government regulations, commodity prices, consumer expectations, market demands, pesticide industry representatives and Pest Control Advisors (PCAs)[3]. Industry standards for aesthetics or quality can influence product selection and application. Environmental causes of pesticide use variation consist of annual and regional fluctuations in rainfall and temperatures, pest outbreaks and soil conditions.

However, variations also occur as a result of grower-specific management practices[4]. Each pesticide application represents a choice made by the grower regarding product, timing, rate and coverage of application. Decisions to cut pesticide use are informed by such diverse practices as fostering beneficial insects, promoting cover crops, and monitoring for the spread of diseases. Some of the differences in pesticide use observed in the PUR might be attributed to: lower use rates made possible by technological advances which apply products more efficiently, as evidenced by Smartsprayer equipment; adoption of ecological management practices which can maintain field sanitation and reduce pest problems, making pesticide use less necessary; identifying pests and diseases for action thresholds; and intentional avoidance of problem pesticides by planning and experimenting with reduced-risk materials. [Reduced-risk is defined according to the Environmental Protection Agency's (EPA) Conventional Reduced-Risk Pesticide Program which reviews 'conventional pesticides that meet criteria which indicate that they pose less risk to human health and the environment than existing conventional pesticides. Conventional "Reduced-Risk" pesticides have one or more of the following advantages over existing conventional pesticides: (1) low impact on human health, (2) lower toxicity to non-target organisms (birds, fish, plants), (3) low potential for groundwater contamination, (4) low use rates, (5) low pest resistance potential, and (6) compatibility with Integrated Pest Management (IPM) practices' (EPA[5]).]

Growers are often the best innovators of new ideas and techniques. Despite a history of university extension that 'deals in universals: principles that are true for all times and places'[6], research institutions are increasingly recognizing that technologies must allow for and be responsive to grower adaptation[7]. Growers are intimately familiar with their agricultural systems and are able to assess the factors affecting production. They must absorb and respond to complex, dynamic and unpredictable conditions[8,9]. The agro-ecological understanding growers learn through time allows them to develop approaches suited to their particular situations. Growers who decrease reliance on chemicals do so through knowledge of local ecological processes[10,11]. Their accomplishments are the result of practical experimentation[12].

Materials and Methods

PUR from 1993 to 2000 (CDPR[1]) were used in this study. Thirty-two data items are recorded in each PUR, including the commodity treated, the number of hectares planted, the number of hectares treated, the active ingredients (AIs), the kilograms of chemicals used, the dates of application, and method of application. Grower and farm level analysis was achieved by tracking the unique identification numbers assigned to growers and their fields. This research project focused on PUR data gathered from prune orchards in Yuba and Sutter counties which border each other north of Sacramento (Fig. 1). These counties were selected for analysis since they are representative of statewide production trends, within the top 80% of total yield for prunes, and serviced by the project's collaborating organizations. Project collaborators include the Community Alliance with Family Farmers (CAFF), The Nature Conservancy (TNC), and the California Dried Plum Board (CDPB).

A Geographic Information System (GIS) program was used to retrieve and organize PUR data. The data were then summarized by county, commodity, and year, and sorted by individual chemicals for the eight-year period between 1993 and 2000 to assess the use trend. Finally, field pesticide applications and grower-specific pest management histories were examined. Fields were chosen as the primary unit of measurement. Pesticides reported on each field were subjected to the qualitative assessment and quantitative measurements described below. Growers were chosen as the primary unit of pest management decision-making.

Qualitative assessments of pesticide use

Two types of qualitative assessments were made for reported pesticide use: by target organism (insecticide, fungicide, miticide and herbicide) and by risk category as established by the Food Quality and Protection Act (FQPA) priority categories I, II and III[5]. FQPA categories I and II are considered higher-risk while category III chemicals are 'soft' pesticides or biopesticides. Insecticides and fungicides were selected for intensive study because they were the most heavily and frequently used chemical types for prunes (by kg of AI) and are being addressed by pesticide reduction and substitution efforts.

Insecticides were separated into dormant and in-season use categories due to differences in exposure risk, water quality concerns, and regulations associated with the rainy versus dry season. The dormant period was defined as December 10 through February 28, while in-season was defined as March 1 through September 30, as suggested by the collaborator from the CDPB. Selected higher-risk insecticides included organophosphates (OPs), and reduced-risk insecticides included oils, *Bacillus thuringiensis* (Bt) and pyrethroids. Higher-risk fungicides included captan, iprodione, chlorothalonil, cyprodinil and propiconazole, and reduced-risk fungicides included sulfur and copper.

Quantitative assessments for individual grower profiles

Two types of quantitative measurements were made for reported pesticide use: use intensity (kg AI per ha crop planted) and use rate (kg AI per ha crop treated). Simple statistics were used for analysis. Three different layers of variations in pesticide use were examined: county, chemical, and grower. First, county-wide trends provided a backdrop of average pesticide use from which to compare best practices. Next, differing use intensities for selected chemicals were examined against the county average to identify innovative growers who chose lower-risk pesticides and demonstrated low use intensity or low use rates. Finally, use intensity for individual AIs was developed by segregating the kg AI per ha crop planted into five categories: very-low, low, moderate, high, and no use. Each category reflects the proportion of use relative to the county average. Very-low use was defined as between 1 and 25% of the county average of the kg AI per ha crop planted of a particular chemical. Low use was defined as 25–50%; moderate as 50–100%; and high as over 100%. No use fields did not use any of the individual chemicals.

In order to identify innovative patterns and trends, a series of filters was applied to the data aggregated at the grower level. The filters included: low to moderate number of AIs of chemical groups of interest; few or no pesticides from the FQPA priority I list; low use rates and intensity of fungicides and insecticides; low number of applications by chemical; low percentage of hectares treated or spot treatments; and consistently low or decreasing rates of use

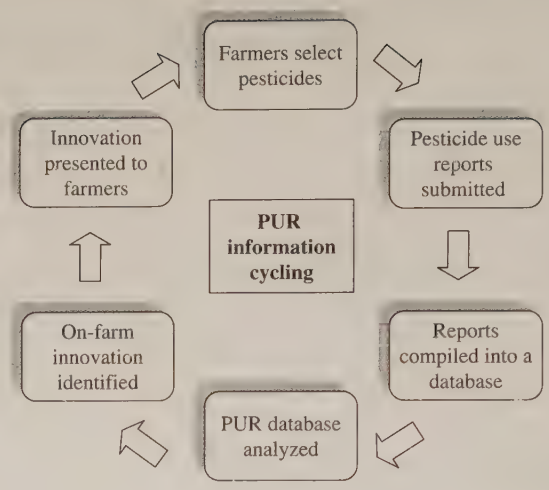

Figure 2. Information cycling of PUR with on-farm analysis.

from 1998 to 2000 to help eliminate young orchards, outliers, and inconsistent practices.

By concentrating on very-low, low, and no use rates, we sought to develop profiles of growers applying especially modest amounts of pesticides. 'Profiles' are a comprehensive log of all chemicals and products applied on each field of a given grower. They describe the schedule of applications by listing the AIs and quantities used, the kg AI per ha crop planted, the percent of the field treated, and the number and date of applications. We searched for growers with low use of higher-risk chemicals and/or use of reduced-risk pesticides. Additionally, growers who showed no use of a particular chemical type were identified. The compound criteria prevented an overly narrow scope by recognizing the numerous avenues through which growers can experiment with reduced pesticide use. This permitted a variety of innovative strategies to surface.

Grower meetings and yield survey

Those growers that persisted after the filtering process were detailed into management profiles for presentation to commodity boards, community organizations and farmers at grower meetings. Collaborative research relationships are an important part of the project methods. The project collaborators participated in the research process at three stages: defining the research parameters, interpreting the results and suggesting practical applications for the outcomes.

Grower participation is especially important. First, in submitting the PUR forms they actively created the database upon which the research is built. Secondly, after initial investigation by the researchers reveals low-use growers, profiles of the applications are taken to grower meetings for evaluation. In the final phase of the research, selected low-use growers are contacted by collaborating organizations and asked to share their management practices through farmer-to-farmer exchanges.

Figure 2 presents the cycling of PUR information and the delivery process that takes place. Growers select and apply

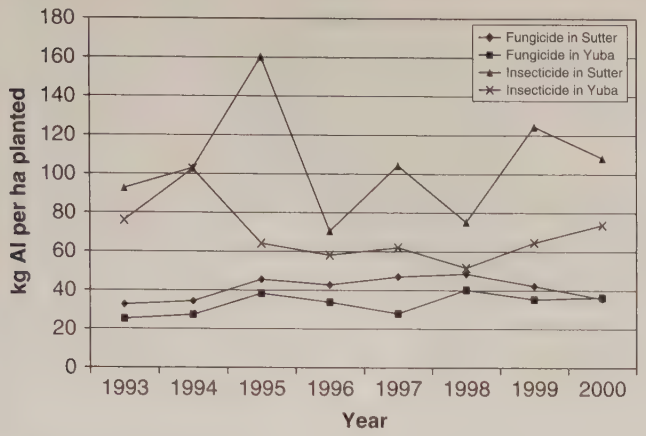

Figure 3. Insecticide and fungicide trends in Yuba and Sutter counties 1993–2000.

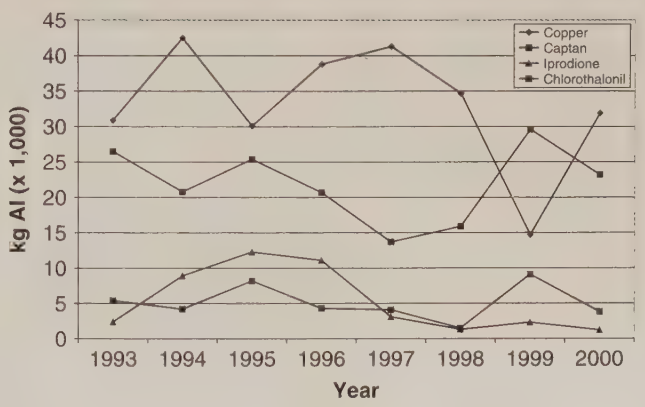

Figure 4. Sutter County fungicide trends 1993–2000.

pesticides, and then submit their use reports to county agricultural commissioners. DPR compiles the reports into a database. Researchers analyze the database, and are assisted in the identification of on-farm innovation by collaborators and farmers. In subsequent research phases, low-use systems are presented to growers interested in reducing pesticide use, bringing the database back to farmers.

Planning and feedback meetings were held among the project collaborators on a quarterly basis between 2001 and 2002. Additionally, an article was published in CAFF's 'Farmer-to-Farmer' magazine to disseminate the preliminary research results and to solicit feedback from interested growers[13]. The ongoing research results were presented first to the CDPB collaborator's project management team members and then to prune growers for their comment and review. The growers requested and participated in a yield survey of those profiles deemed of interest, and volunteered information to validate the use of these profiles. Yield data and orchard age from six growers with contrasting profiles were obtained for 1999 and 2000, and matched with the pesticide use records.

Results

County trends from 1993 to 2000 for Yuba and Sutter indicated that the two counties had similar overall pesticide use as expressed by kg AI per ha crop planted (Fig. 3). Fungicide use increased from 25–35 kg ha^{-1} to close to 40 kg ha^{-1} for both counties, while insecticide use fluctuated over the time period with higher use intensities in Sutter County than in Yuba County (Fig. 3). Large variations were observed in insecticide use for the two counties. Analysis of data aggregated by fields and growers demonstrated evidence of pesticide use reduction as well as substitution trends towards reduced-risk products (Fig. 4). In Sutter County, copper use increased as captan use decreased (Fig. 4). The use of iprodione increased in early 1995 and then decreased after 1996. The use of captan showed a decreasing trend during the mid-1990s followed by a sharp increase in 1999, a wet year.

Both counties exhibited variability in pesticide use at the field and grower management levels. There are a significant number of low-use growers in each county, even after accounting for variations in geographical location within the county and acreage under cultivation (Fig. 5). The map in Figure 5 displays the distribution of the aggregated field use intensity for each of the 68 growers in Yuba County and 226 growers in Sutter County in 2000. Low, moderate, and high use growers are randomly dispersed throughout the two counties. It also demonstrates the trend towards low to medium use categories. Table 1 presents the aggregated pesticide use intensity of large growers (over 80 ha) in both counties in 2000 and their distribution within the use categories. In Sutter County, 23% of large growers were very-low or low use, 18% were moderate, and 59% were high. In Yuba County, 15% were very-low or low use, 40% were moderate, and 45% were high. The larger trend towards moderate use in Yuba County is explained in part by the fact that a higher overall percentage of growers were large as compared with Sutter; however, both counties make clear that low and moderate use intensities persist even when examining large-scale operations and are not simply a phenomenon of smaller farms.

In Yuba County during 2000, 4.5% of fields used no insecticides, 38% of fields used no fungicides, and 74% of fields used no herbicides. In the 2000 data for Sutter County, 9% used no insecticides, 25% used no fungicides, and 77% of fields used no herbicides. These fields represented a diversity of pesticide use patterns. Their use categories ranged from very-low to high for the AIs they did apply. Newly planted orchards and growers with small acreages were not examined, but growers who demonstrated a pattern of no use over time were analyzed in detail over 3 years. These results were significant in that they were unanticipated by the CDPB collaborators, demonstrating lower than expected use of fungicides and herbicides. Fungicides are applied preventatively, but the considerable number of no fungicide fields (38%) suggests that outreach and education efforts promoting disease monitoring have had a positive impact on pest management decision-making.

In Sutter County, 362 out of 472 fields and 98 out of 133 fields in Yuba County in 2000 showed no herbicide use.

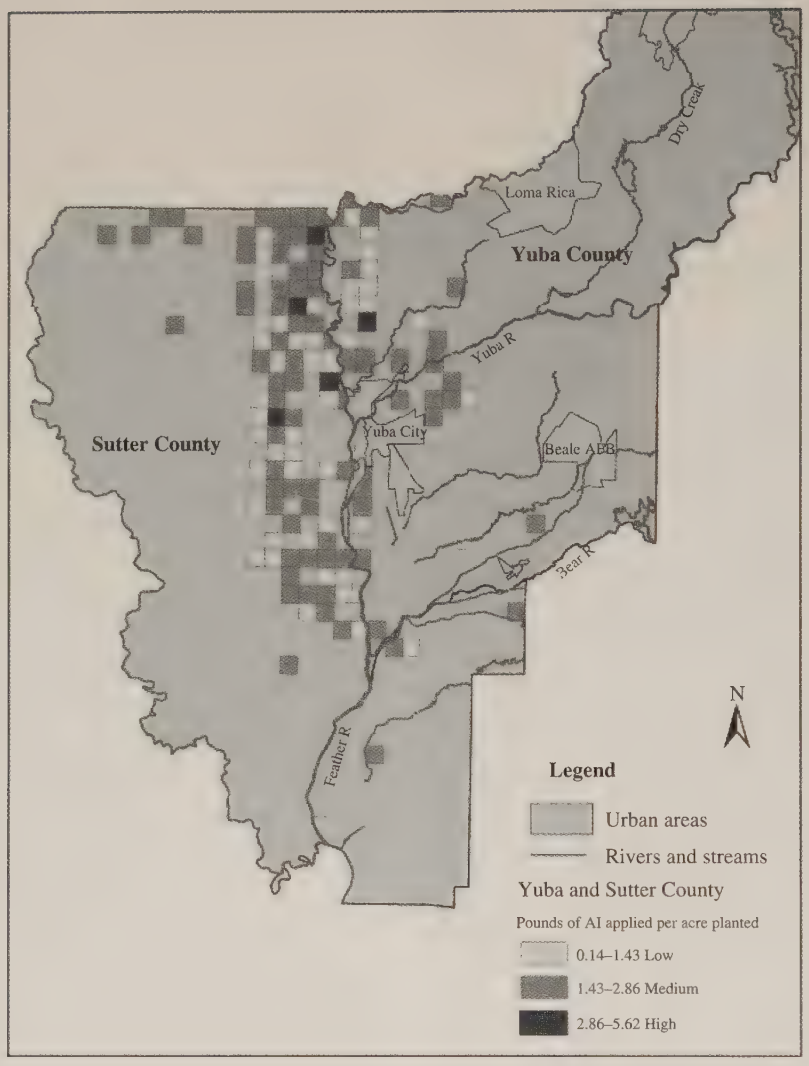

Figure 5. Geographic distribution of aggregated field use rates in 2000.

Table 1. Pesticide use intensity of large growers (>200 acres) in Sutter and Yuba in 2000.

	Sutter County			Yuba County		
Pesticide use categories	**No. of growers**	**Total ha**	**Pesticide use intensity (kg ha^{-1})**	**No. of growers**	**Total ha**	**Pesticide use intensity (kg ha^{-1})**
County	226	9310	26.24	68	5076	31.19
Very low	2	478	5.16	1	63	2.15
Low	3	332	10.05	2	333	8.87
Moderate	4	915	20.46	8	1517	18.12
High	13	2344	45.69	9	2082	31.76
Sub-total	22	4069	32.35	20	3995	24.21

The no herbicide use fields were spread over a wide spectrum of growers, so while low fungicide and insecticide use was the primary focus of analysis, low or no herbicide use became an additional measure. The no herbicide use results suggest mowing and discing for weed control, use of cover crops and grass for beneficial insect habitat, and/or tolerance of some weed growth. Low herbicide use often reflected spot treatments, possibly in-row spraying and between row mowing, a method which has been identified among innovative growers[14] and encouraged by commodity and community organizations as reduced-risk.

Tables 2 and 3 display the number of fields that fell into the low to high use categories for insecticides and fungicides in Yuba and Sutter County prunes in 2000. They

Table 2. Number of fields using selected insecticides and fungicides in Yuba County prunes in 2000 ($n = 133$).

Pesticide use categories	Insecticides dormant (December 1 to February 28)				Insecticides in-season (March 1 to September 30)				Fungicides entire year						
	OP	Oils	Bt	Pyrethroids	OP	Oils	Bt	Pyrethroids	Captan	Iprodione	Chlorothalonil	Cyprodinil	Propiconazole	Sulfur	Copper
Very-low	4	4	0	1	0	2	0	0	0	0	0	0	0	2	0
Low	4	6	0	4	2	2	0	2	1	0	0	2	2	2	0
Moderate	19	29	0	17	10	7	0	9	24	7	2	13	8	7	3
High	26	36	0	22	5	23	4	30	23	2	1	18	21	11	5
Total no. fields using pesticides	53	75	0	44	17	34	1	41	48	9	3	34	31	22	8
% of total fields	40%	56%	0%	33%	13%	26%	1%	31%	36%	7%	2%	26%	23%	17%	6%
No use fields	80	58	133	89	116	99	132	92	85	124	130	99	102	111	125
Average kg per ha planted	1.6	16.99	0	0.036	1.2	27.77	0.21	0.04	2.32	0.75	2.32	0.18	0.097	13.09	7.54

Table 3. Number of fields using selected insecticides and fungicides in Sutter County prunes in 2000 ($n = 472$).

Pesticide use categories	Insecticides dormant (December 1 to February 28)				Insecticides in-season (March 1 to September 30)				Fungicides entire year						
	OP	Oils	Bt	Pyrethroids	OP	Oils	Bt	Pyrethroids	Captan	Iprodione	Chlorothalonil	Cyprodinil	Propiconazole	Sulfur	Copper
Very-low	5	22	0	6	6	7	0	5	4	0	1	2	2	4	16
Low	8	30	0	13	8	1	1	13	15	2	5	5	6	9	8
Moderate	55	116	0	117	14	6	7	7	71	19	14	57	33	49	29
High	81	176	0	72	38	11	4	22	109	18	19	49	65	44	30
Total no. fields using pesticides	149	344	0	208	66	25	12	47	199	39	39	113	106	106	83
% of total fields	31%	73%	0%	44%	14%	5%	3%	10%	42%	8%	8%	24%	22%	22%	18%
No use fields	323	128	472	264	406	447	460	425	273	433	433	359	366	366	389
Average kg per ha planted	1.46	18.77	0	0.046	1.46	13.84	0.08	0.025	2.53	0.56	2.16	0.17	0.093	12.98	8.51

also list the number of fields not using any of the individual chemicals ('No Use'). Most fields used pesticides at more than 50% of county average use rates, so they were grouped into moderate and high use intensity. However, five fields out of a total of 68 were found to use OPs and pyrethroids at low rates during the dormant season, and four fields were found to use low rates of sulfur during the in-season. It is interesting to note the high percent of no use fields for each chemical. Although higher-risk insecticides and fungicides, such as OPs and Captan, were more frequently used than reduced-risk AIs (with the exception of oil), pyrethroids, and sulfur were used by a significant number of fields. Variations in intensity between Yuba and Sutter, such as copper, dormant oil, in-season oil, and pyrethroids, are reflected in the differences in low-use profiles for each county.

The individual field use rates for each of the AIs listed in Tables 2 and 3 were then grouped by grower ID, making it possible to determine which growers used the fewest AIs at the lowest rates (these tables are not shown due to the large volume of data involved). This analysis helped highlight variations between and among growers, growers with similar use patterns across each of their fields, and differing strategies between a grower's fields. New orchards, organic fields, and non-productive or abandoned orchards were eliminated. Records were traced over a 3-year period to show consistency in the use patterns, to remove outliers, and to account for annual weather fluctuations and the associated impact on pest pressure and pesticide use.

From this process, 16% of the prune growers in Yuba County and 8% of the growers in Sutter County could be identified as low pesticide users. The following are examples of reduced chemical use summarized from the profiles:

- Transition to reduced-risk insecticides and fungicides from diazinon, sulfur, and propiconazole in 1998 to Bt, oil, and copper in 1999, to Bt alone in 2000.
- Reduction in AIs such as diazinon, sulfur, and propiconazole used in 1998 and 1999, to oil and esfenvalerate only in 2000.
- Consistent trend of low oil/esfenvalerate use over the 3-year period.

Since the AIs alone cannot express the management decisions behind them, the data were then taken to project collaborators for interpretation.

Insect and disease pressure fluctuate annually, and may partly explain the different use of AIs from one year to the next. However, the transition from higher-risk AIs to reduced-risk AIs suggests intentional substitution, as has been proposed by previous studies[15,16]. For example, the pattern in the first profile example above suggests a replacement of an OP with Bt during bloom time to control peach twig borer. Diazinon is used to target San Jose scale, peach twig borer, leaf curl plum aphid, and mealy plum aphid, and is sprayed during the dormant season. This coincides with California's rainy season, and diazinon is a key focus of storm run-off and water pollution prevention efforts. The increased use of esfenvalerate in the second example may represent a choice towards reduced environmental impact as it is an AI with compound functions.

Due to the influence of multiple factors, pest management is highly variable among growers and regions. However, there were patterns of management practices among growers. Table 4 provides a sample profile of a grower in Sutter County whose management practices emphasize reduced-risk fungicides and show a trend towards reduced use of sulfur. Table 4 represents only the 2000 data, as the 1999 and 1998 are too lengthy to also be included. This grower has 65.6 ha under cultivation and spread 29 applications over eight fields in 2000. The grower used ten AIs, with an average of three AIs per field. Fungicide use was limited to sulfur and copper hydroxide, both of which are reduced-risk chemicals. Similarly, Bt and petroleum oil were the only insecticides used. Five out of the nine herbicide applications were spot treatments. The sulfur could be applied to target powdery mildew and the copper hydroxide to target peach leaf curl. Bt and oil were both only applied once on two fields, suggesting monitoring for pest thresholds rather than preventative applications. The Bt was applied in late March at a time coinciding with peach twig borer larvae emergence.

In contrast, a sample profile of average pesticide use can be seen in a Sutter County grower who used higher-risk chemicals, more AIs per field, and higher rates per chemical (the complete profile is not shown due to the large volume of data involved; however Table 5 presents a sample profile of one of the five fields). This grower had 111.6 ha under cultivation and spread 74 applications over five fields in 2000. This grower used 19 AIs, with an average of 13 AIs per field. This included two chemicals targeted for reduction: captan and methyl bromide. Insecticides, fungicides and herbicides were used on each field, generally at average to high rates with a high percent of hectares treated. The methidathion was likely applied to control San Jose scale, the captan brown rot or green fruit rot, and the methyl bromide to control nematodes.

Information exchange

After the analysis, the results were shared with project collaborators and farmers for interpretation and verification. Profiles like the one in Table 4 were used to deliver specific pesticide use histories of low use growers and hypothetical pest management practices. The profiles provided a comprehensive snapshot of low use records. When presented at grower meetings they proved to be an effective means of distributing information to farmers. The relevance of the profiles selected was discussed by analyzing the number of hectares under cultivation, differences in management practices between fields, AI combinations and target pests, and variations in use between years to verify that these practices were consistent with successful low pesticide use.

Table 4. Sample low-use profile, Sutter County 2000.

AI	No. of applications	Acres treated	kg AI per ha planted	County average	% ha treated
13 acres planted					
Sulfur	1	13	4	11.27	100%
Petroleum oil	1	13	42.38	21.5	100%
20 acres planted					
Sulfur	2	40	12	11.27	200%
40 acres planted					
Glyphosate	1	4.24	0.113	0.94	11%
Sulfur	1	78	11.7	11.27	195%
Petroleum oil	1	39	41.35	21.5	98%
Paraquat	1	4.71	0.076	0.43	12%
Bt	1	40	0.064	0.061	100%
10 acres planted					
Sulfur	2	10	12	11.27	100%
Paraquat	1	10	0.433	0.43	100%
Oryzalin	1	10	1.32	0.7	100%
20 acres planted					
Paraquat	1	20	0.433	0.43	100%
Oryzalin	1	20	1.32	0.7	100%
20 acres planted					
Sulfur	2	20	16	11.27	100%
Petroleum oil	2	20	63.63	21.5	100%
Copper-hydroxide	1	20	6.14	4.56	100%
Lime-sulfur	1	20	15.58	15.58	100%
Bt	1	10	0.05	0.091	50%
15 acres planted					
Sulfur	2	13	10.4	11.27	87%
Petroleum oil	1	13	28.27	21.5	87%
26 acres planted					
Glyphosate	1	4.3	0.69	0.94	23%
Paraquat	1	11.56	0.33	0.43	44%
Oryzalin	1	4.3	1.02	0.7	17%
Oxyflourfen	1	4.3	0.02	0.44	17%

Table 5. Sample high use profile, Yuba County 2000.

AI	No. of applications	Acres treated	kg AI per ha planted	County average	% ha treated
78 acres planted					
Isopropyl alcohol	1	78	0.01	0.037	100%
Methidathion	1	78	1.04	1.18	100%
Compounded silicone	1	78	0.004	0.045	100%
Captan	1	78	3.00	2.33	100%
Octyl phenoxy	1	78	0.08	0.2	100%
Mineral oil	1	78	12.41	21.5	100%
Cyprodinil	1	78	0.234	0.17	100%
Sulfur	1	78	9.7	11.27	100%
Paraquat	1	78	0.20	0.43	100%
Poly-I-paramenthene	1	78	0.36	0.36	100%
Methyl bromide	1	78	2.19	5.46	100%
Glyphosate	1	18	0.356	0.94	23%
Oryzalin	1	18	0.92	0.69	23%
Strychnine	1	30	0.0029	0.0039	38%

During a presentation of the initial results in Yuba County, growers suggested that socio-economic (pesticide costs) and environmental reasons (proximity to rivers and streams) as well as management practices might explain some of the variation in pesticide use. Growers acknowledged familiarity with the decisions behind the profiles presented, and several discussed their own experiments with reduced-use, including an esfenvalerate/oil combination. Coincidentally, one of the profiles presented at the meeting was that of a grower in attendance who is recognized for his success with alternative management systems.

It was acknowledged by farmers, regulators and scientists that it is difficult to determine if the profiled growers are viable models without corroborating economic and agronomic factors. One grower proposed that by tracing the pesticide use history and showing consistently low or decreasing rates of use, some proof of economically sensible management had already been established.

Yield data from six growers (based on their availability at the date of the field interview) from Sutter County shows that low pesticide use was not an impediment to high yield. Of the six growers surveyed, two had below average yields in 2000, two were at or above average, and two were significantly above average. One of the below average-yield growers had only 11.2 ha under production, and over half of the fruit was either under-sized or had pest damage. The other below average-yield grower experienced severe brown rot in the mid-1990s which damaged the trees. Both of the average-yield growers had young orchards and one of them experienced frost damage in 1999. Each of the high-yielding growers consistently had yields at or above 6700 kg ha^{-1}, when the average prune yield was 5400 kg ha^{-1} in Sutter County in 2000. One of these growers had seven fields, used no FQPA I or II chemicals, and yielded an average of 6900 kg ha^{-1}. The other low-use grower had 13 fields and averaged 7400 kg ha^{-1}. To provide a point of comparison, a grower identified as a moderate to high pesticide user with 20 fields used high rates of diazinon and yielded 7200 kg ha^{-1}.

With the assistance of the CDPB collaborator, several of the low-use growers were contacted and field visits made. For example, the low-use grower described above with 13 fields and an average of 7400 kg ha^{-1} does not use herbicides in his floor management plant. Instead, he uses oats and vetch, and a reseeding of radishes and mustard, as a winter cover crop. Prunes do not require clean orchard floors for harvest, and most of the cover crop is allowed to reseed before being mowed. Discing between and within the rows is used to help control perennial and summer vegetation, but the grower uses a 'green' orchard floor approach. He partially attributes his low use of insecticides to the beneficial insect habitat provided by his cover crop. Because he dries and packs his own fruit, he does not risk having his fruit rejected by the processor. He can therefore tolerate a certain level of damage without feeling pressured to treat his orchards. This, in turn, provides a positive feedback loop by promoting high levels of beneficial insects which give him excellent fruit quality. During the yield survey, this grower demonstrated higher than average yields, which he attributed to younger trees, appropriate varieties, and good pruning and irrigation practices. Similar innovative methods that rely on comprehensive grower management have been observed in winegrapes using the PUR analysis and were also confirmed with on-farm field visits and interviews[17]. Field visits give researchers the opportunity to learn about the decision-making process behind reduced pesticide use first-hand from growers, providing empirical data to explain use choices.

Discussion and Conclusion

Unlike a designed field experiment, this research project is unique in that the entire population of prune growers in the two counties selected was used for the data set. Aggregation of the data at the level of individual growers allowed for identification of distinct management styles. Three major conclusions can be drawn from the research results. The first significant result is that low-use systems can be successfully identified with the PUR database. Secondly, profiles of innovative pest management strategies can be synthesized from the vast PUR data. Finally, profiles are an effective means for transferring the research information to growers in partnership with project collaborators.

In addition to their value for tracking general use trends, the PUR document variations among individual growers[1]. Each PUR reflects part of a grower's overall farming approach. Analyzing individual farmers' pesticide management strategies allows the differences between growers to emerge. The variations in pesticide use documented by the PUR suggest that some growers have developed best management practices which emphasize the use of reduced-risk pesticides and draw on integrated approaches for pest and disease control[4,18]. Identifying successful innovation with the PUR can lead to pragmatic interpretation of the database for use by farmers. Growers interested in reducing pesticide use can draw on the application histories recorded in the PUR to adapt best management practices on their own farms[4]. In his study of California participatory partnerships, Warner concluded that knowledge exchange between growers is an effective means of information and technology transfer to reduce pesticide use[7]. The next phase of this project will emphasize the final stages described in Figure 1. Specifically, future research should analyze the success of various information exchange methods of presenting the PUR profiles, as measured by adoption rates of on-farm innovation models.

There were sufficiently large numbers of low-use patterns and growers in each county to allow the analysis to emphasize low quantity and low toxicity pesticide use. Low-use systems can be explained by a number of different factors, including cultural practices and choice of safe chemicals. For example, low or no use of herbicide may indicate cultivation of a cover crop, discing, or mowing for weed control. Growers who understand the ecology of

prey–predator relationships may need fewer insecticides. The PUR database documents the timing of applications, which can help establish if the product is being used preventatively or to treat an existing problem, and if pest monitoring practices are being employed to avoid unnecessary applications[11]. This can be important when thinking about the impacts of pesticide use on water and air quality.

Commodity groups are essential liaisons between university researchers and farmers. They are especially helpful in contacting identified growers to inquire about their practices and their willingness to share them. Although PUR data are public information, there is often an expectation of privacy among farmers filing the reports. Thus, when profiles are presented at grower meetings, confidentiality is maintained by keeping the information anonymous. Collaborators can then follow up with the identified low use growers to develop a mechanism for farmer-to-farmer field days or other information sharing venues.

A challenge revealed by the research process has been the mixed reactions to the low-use profiles. This has been true in situations in which the profiles gave evidence of low-use systems not commonly understood or recognized within the outreach and education community. Commodity group collaborators were sometimes surprised at the result, particularly when the data revealed lower than recommended application rates. Instead of finding pesticide use clustered around recommended application rates as expected, the analysis revealed that the recommended rates reflect the upper limits of use. There was a tendency by some growers to attribute the low pesticide use to poor judgment. On the other hand, many growers expressed familiarity with the management systems behind the profiles, and expressed confidence in them.

Another limitation is that not all farmers identified through the analysis system are in fact good models: priorities other than reduced-use can determine pesticide management decisions. For example, part-time farmers do not adequately reflect the challenges of making a living from farming and may have low pesticide use as a consequence of limited management. Additionally, poor yields or low fruit quality may be associated with reduced pesticide use. Researchers must interview growers to determine if differences in use between years or trends across time are a reflection of differences in pest pressure or a conscious move towards low use.

Evaluating crop yields and quality is essential to validating pesticide use reduction. According to a CDPR Pest Management Alliance (PMA) report on almonds, reduced use of pesticides did not increase crop damage[19]. Our preliminary yield data indicate that while a few innovative growers did have sub-optimal yields, most had average or above-average results. Additional research should determine if pesticide use can be further reduced by disseminating information about best management practices for low pesticide use through farmer networks to a wider group of growers, and if yields are affected.

Mining the PUR was a successful means of identifying growers with innovative, low pesticide use management strategies, including decreasing numbers of AIs, spot treatments of higher-risk chemicals, and transition to reduced-risk products. The combined efforts of university researchers, community and commodity organizations, and growers resulted in a framework for collaboration. Summarizing the extensive PUR data into individual profiles made the PUR database an accessible tool for disseminating information about best management practices.

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Farmer perceptions of soil quality and their relationship to management-sensitive soil parameters

J.B. Gruver[1,2,*] and R.R. Weil[1]

[1]Department of Environmental Science and Technology, University of Maryland, College Park, MD 20742, USA.
[2]Department of Agriculture, Western Illinois University, Macomb, IL 61455-1390, USA.
*Corresponding author: jgruv@hotmail.com

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Abstract

A critical step in the quantification of soil quality (SQ) is the selection of SQ benchmarks. The benchmarks used in this study were SQ ratings made by 32 farmer collaborators representing a range of farming systems, scales of operation and geographic locations in the Mid-Atlantic region of USA. Soils from 45 pairs of sites identified by their farmers as having good and poor SQ were sampled over three seasons and analyzed for 19 soil parameters. Farmer judgments of SQ were based on many factors, most commonly soil organic matter, crop performance, soil water availability and erosion history. Selected individual soil parameters were normalized and integrated into an additive SQ index (SQI). Three additional indices were developed using discriminant analysis. The level of agreement between individual parameters, SQIs and farmer SQ ratings was evaluated using paired *t*-tests and mean percent difference values. The additive SQI was found to have the highest level of agreement with farmer SQ ratings ($P < 0.0001$), demonstrating that a linear combination of soil parameters can be assembled that is more in agreement with holistic SQ criteria, such as farmer SQ ratings, than individual soil parameters. Extractable C from microwave (MW) sterilized soil (a measure of microbial biomass) was the individual parameter that best agreed with farmer SQ ratings ($P < 0.0001$). Five additional soil C parameters, as well as aggregate stability, also agreed well with farmer SQ ratings (all P values < 0.0005). The three parameters with the highest ratio of mean percent difference to coefficient of variation (an indication of parameter reliability) were extractable C from MW sterilized soil, anthrone reactive C and macroaggregate stability (14.2, 7.7 and 3.7, respectively). Mineral fertility parameters (pH, Ca, Ca : Mg ratio, P and K) were not significantly related to farmer SQ ratings (P values > 0.05). The strong relationships observed between soil C parameters, soil structural parameters and farmer SQ ratings suggest that efforts to improve SQ in the study region should focus on monitoring and enhancement of soil C and soil structure.

Key words: soil quality index, farmer perceptions, soil structure, soil aggregation, extractable soil C, microbial biomass

Introduction

A basic assumption underlying the concept of land stewardship popularized by Aldo Leopold[1] is that local knowledge of soil and other natural resources is the foundation of sustainable land management. A logical extension of this view is that farmer knowledge is a valuable resource that can contribute to the scientific investigation of soil quality (SQ). Several recent studies[2,3] have proposed that farmer assessments of SQ are a useful antecedent to more technical investigations. Other studies[4,5], however, have identified poor agreement between farmer perceptions and technical descriptions of soil and cautioned that misunderstanding of scientific principles impedes problem solving by farmers. Integration of experiential knowledge (e.g., farmer understanding of soil) with scientific methods is clearly challenging, but may be essential for understanding holistic concepts such as SQ.

Understanding how farmer perceptions of soil relate to objective soil properties is key to using farmer knowledge as a resource in the scientific investigation of soil. Ethnopedologists have identified strong relationships between indigenous soil classification systems and chemical and physical soil parameters[6]. Perhaps even more importantly, however, indigenous soil classification systems distinguish the soil characteristics that guide local management[7]. Often constraints and opportunities can be identified

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when local perceptions of soil contrast with scientific assessments[8].

Several recent studies[2,4] have indicated that farmers in the US have limited understanding of the technical characteristics of the soils they manage. A survey of 745 farmers in Wisconsin found a low level of agreement between farmer responses and profile characteristics of the solum at Natural Resource Inventory sampling points in their fields[4]. This is not surprising, however, as farmers interact primarily with surface soil and rarely use the esoteric soil science terminology included in the survey. In eastern Nebraska, Liebig and Doran[2] evaluated the accuracy of SQ assessments by 24 farmers of paired sites ('good' and 'poor' soils) with respect to field descriptive, field analytical and laboratory-analytical assays of soil. Farmer assessments were 'correct' or 'near correct' greater than 75% of the time for most soil parameters, but were less accurate for 'poor' soils than 'good' soils and particularly inaccurate for intangible soil properties such as available N and P.

Several regional SQ research initiatives[9,10] have used farmer perceptions of soil as a central resource. The Wisconsin Soil Health Program (WSHP) was initiated in 1990 and involved more than 100 Wisconsin farmers in a collaborative effort to gather, analyze and utilize farmer perceptions of soil[9]. One WSHP activity used a series of structured questions to identify how a select group of 28 farmers recognize healthy soil[11]. Another WSHP activity was the development of the Wisconsin Soil Health Scorecard, a checklist of soil health indicators accompanied by distinct scoring criteria[12]. The Illinois Soil Quality Initiative (ISQI) was established in 1990 and monitored physical, chemical and biological soil characteristics under different cropping systems and environmental conditions[10]. Collaborating farmers participated in evaluating soil data, developing new directions for SQ research and communicating SQ concepts to a wider audience[10]. These programs and others that have involved farmers in SQ research recognize that farmers implement the practices that improve, maintain or diminish agricultural SQ[13].

The terms 'soil quality' and 'soil health' have often been used synonymously[14] to describe the concept of 'soil fitness to perform important soil functions'[15]. While some semantic distinctions between the two terms have been presented in the literature[16,17], we offer the following differentiation to encourage greater linguistic precision in future discussions. *Soil quality* is a utilitarian term that describes compatibility between a soil's properties and valued services performed by soil. These soil properties include both inherent[18] *alias* use-invariant[19] and static[20] properties (e.g., texture, mineralogy, landscape position) and management-sensitive *alias* use-dependent[19] and dynamic[18] properties (e.g., organic matter content, biological activity, aggregate stability). In contrast, *soil health* is an ecological term that describes the extent to which a soil fulfils key criteria of biological integrity (e.g., self regulation through feedback processes and freedom from distress symptoms)[21,22]. Thus, *soil quality*, with its utilitarian orientation, is the appropriate term when discussing farmer perceptions of soil performance in agricultural production systems.

Some studies have quantified SQ using single soil parameters with broad ecological impact, such as microbial biomass[23] and active organic matter[24]. Other studies have quantified SQ using mathematical functions that vary with respect to techniques for selection (e.g., key functions[25], best-fit regression[26], power analysis[27]), weighting (e.g., threshold values[25], data set maximums[26], scoring functions[25]) and integration (e.g., additive[25,26], multiplicative[28]) of multiple parameters. Most integrative models are subjective (i.e., dependent on the priorities and judgments of investigators).

A critical step in the assessment of SQ is the identification of SQ benchmarks. Within the traditional 'soil productivity equals SQ' paradigm, high yields are a benchmark of SQ. More holistic concepts of SQ attach importance to environmental quality and soil fitness for uses other than agriculture[3]. Some studies[29–31] have used soil conditions under native vegetation as SQ benchmarks. Harris and Bezdicek[16] proposed that farmer observations and judgments of SQ could serve as the foundation for a SQ index (SQI). The present study used farmer ratings of SQ as benchmarks for evaluating the relationship between management-sensitive soil parameters and SQ. Unlike studies[2,4,5] which evaluated the accuracy of farmer perceptions, this study started with the premise that SQ ratings by recognized land stewards encapsulate valuable experiential knowledge.

The primary objective of the study was to identify management-sensitive soil parameters and SQI models that agree well with farmer SQ ratings. A secondary objective was to document field indicators of SQ used by farmers and farmer perspectives regarding best management practices for SQ.

Materials and Methods

Selection of farmers

Between the summer of 1996 and the fall of 1997, 75 Mid-Atlantic farmers recognized for their interest in soil conservation were identified as potential farmer collaborators by county extension agents, Natural Resources Conservation Service (NRCS) conservationists or the authors. During short informal telephone interviews, perspective farmer collaborators were asked to identify paired sites on their farms or adjacent land that they perceived to have the same soil type but contrasting SQ. SQ was briefly defined as 'fitness to perform important soil functions'. It was stipulated that paired sites should be mapped as the same (or very similar) soil series, so as to reduce the likelihood that differences in inherent properties (e.g., texture, slope and drainage) would obscure relationships between management-sensitive soil properties and

Table 1. Location, mapped soil series, main contrasting feature and season sampled for all paired SQ contrast sites.

Farm no.	Mapped soils	Pair no.	Main contrasting SQ characteristic	Season sampled		
				f96	s97	f97
1	Glenelg	1	Alfalfa versus NT[1] corn	◆	◆	◆
2	Sassafrass	2	Higher yield versus lower yield	◆		
3	Penn	3	Higher yield versus lower yield		◆	◆
4	Urbana	4	More pest damage versus less pest damage		◆	◆
5	Glenelg	5	Timothy for 6 years versus timothy for 1 year			◆
6	Fauquier	6	42 years of NT versus neighbor's field	◆	◆	◆
7	Matapeake	7	Fescue sod versus CT[2] row crops		◆	◆
	Matapeake	8	Drought stressed corn versus healthy corn			◆
8	Collington	9	Grazed pasture versus hay field			◆
9	Urbana	10	Rye cover crop versus no cover crop	◆		
10	Chester	11	NT with cover crop versus CT w/o cover crop		◆	◆
	Meadowville	12	>30 years NT versus 15 years NT		◆	◆
	Chester/Glenville	13	History of CT versus >30 years NT		◆	◆
11	Sassafrass	14	Good tilth versus poor tilth			◆
12	Westphalia	15	Poor pasture versus good pasture	◆	◆	◆
13	Myersville/Fauqu.	16	Poor pasture versus good pasture			◆
14	Manor	17	Eroded strawberries versus sodded lane		◆	◆
15	Fauquier	18	Higher yield versus lower yield	◆	◆	◆
	Myersville/Fauqu.	19	Higher yield versus lower yield	◆	◆	◆
16	Nolichucky	20	Permanent pasture versus NT corn	◆	◆	◆
17	Nolichucky	21	Poor pasture versus good pasture	◆	◆	◆
18	Chester	22	NT corn silage versus CT flowers		◆	◆
	Chester	23	Full rate manure versus low rate manure	◆		
19	Hagerstown	24	Cover crop versus no cover crop	◆		
20	Mt Airy	25	Hay versus NT corn rotation			◆
	Mt Airy	26	Hay versus NT corn rotation			◆
21	Glenelg	27	Higher manure rate versus lower rate	◆	◆	
22	Mt Airy	28	History of orchard versus strawberries			
23	Chester	29	Good tilth versus poor tilth	◆	◆	
	Chester	30	CT org.[3] vegetables versus chisel corn/soy	◆		◆
24	Sassafrass	31	Higher yield versus lower yield	◆		
25	Woodstown	32	Alfalfa versus row crops	◆		
26	Pocomoke	33	Poor yield versus good yield			◆
27	Chester	34	Eroded vegetables versus field crops	◆		
	Glenelg	35	Poor pumpkins versus old Xmas tree sod	◆		
	Glenelg	36	Higher yield versus lower yield	◆		
28	Sassafras	37	Alfalfa grass sod versus small grain/soy	◆	◆	
	Fallsington	38	Irrigated crops versus non-irrigated crops	◆		
	Sassafras	39	Higher yield versus lower yield	◆	◆	
29	Matapeake compl.	40	Agronomic versus spinach		◆	
	Matepeake compl.	41	Agronomic versus spinach		◆	
30	Hagerstown	42	Compost versus no compost	◆	◆	◆
31	Penn	43	Corn/orchard grass versus alfalfa/NT corn	◆		
	Penn	44	Digestor liquids versus digestor solids	◆	◆	◆
32	Bucks	45	Good yield versus poor yield		◆	

[1] NT = no-till.
[2] CT = conventional tillage.
[3] org. = certified organic.
f96, fall 1996; s97, spring 1997; f97, fall 1997.

farmer SQ ratings. Forty-five paired sites on 32 farms were selected for inclusion in the study (Table 1) based on farmer interest and ability to identify contrasting sites and our goal of including soils from farms with a range of enterprises and scales of operation (Table 2) across the Mid-Atlantic.

During initial farm visits, farmers showed the investigators the paired sites that they perceived to have contrasting SQ (Table 2). Some of the contrasting sites were adjacent fields while others were distinct areas within the same field. Farmers were interviewed at the sites about (1) the management history of each site, (2) evidence

Table 2. Type and scale of enterprises associated with the participating farms.

Enterprise	No. of farms	Scale of crop enterprise		Scale of animal enterprise	
		min	max	min	max
		----------ha----------		----------animal units----------	
Cash grains	21	20	2800	–	–
Vegetables	9	4	140	–	–
Cash hay	6	<20	400	–	–
Fruits	3	0.4	24	–	–
Dairy	9	–	–	70	2260
Beef	6	–	–	50	150
Hogs	1	–	–	na	100
Poultry	1	–	–	na	1000

of SQ differences between paired sites and (3) best management practices for improving SQ. Interviews were informal and responses were transcribed in the field. All paired sites included in the study were of similar landscape position. All but three paired sites were mapped as the same series with the remaining three mapped as different but similar soil series (e.g., Chester and Glenville silt loams).

Soil sampling and processing

Soil samples were collected from 45 pairs of sites on 32 farms located in five mid-Atlantic states (26 in Maryland, 1 in Delaware, 2 in Pennsylvania, 2 in Virginia and 1 in West Virginia). The farms were located in three physiographic provinces: 8 in the mid-Atlantic Coastal plain, 15 in the Piedmont and 9 in the Ridge and Valley province. According to NRCS county soil survey maps, 22 different soil series were sampled (Table 1).

Soil samples were collected one, two or three times from paired sites, depending on the initial sampling season. Samples were collected prior to spring tillage or planting and after harvest but before tillage in the fall, so as to avoid periods of recent physical disturbance. At the time of each sampling, 12–14 cores (0–7.5 cm, total composite volume = 380 cm^3) were collected from each site using a fully enclosed zero contamination JMC soil probe (Clements Associates, Inc., Newton, IA). When row crops were sampled, an equal number of row and inter-row soil cores were collected. Samples were sealed in plastic-lined bags and transported on ice to a cold storage facility where they were stored at 5°C until processed.

The fresh weight of each soil sample was recorded and the gravimetric moisture content was determined by mass loss after drying approximately 10 cm^3 of soil to constant mass in a microwave (MW) oven. The remaining soil was gently crumbled through a sieve with 4 mm openings. Approximately 100 g of soil were returned to the original plastic-lined bag and reserved for analysis of macroaggregate stability. The remaining soil was passed through a sieve with 2 mm openings, analyzed for gravimetric moisture content (method described above) and then transferred to a new plastic-lined bag. Both bags of soil were stored at 5°C until needed for analysis.

Soil analyses

Within two weeks of sampling, moist soil (<2 mm) was analyzed for the following labile C parameters: 0.5 M K_2SO_4 extractable C from MW sterilized soil (C_{MW})[32], 0.5 M K_2SO_4 extractable C from unmicrowaved soil (C_{NMW})[32], anthrone reactive C (C_{AR})[33] in 0.5 M K_2SO_4 extracts of MW sterilized soil (C_{AR}) and substrate induced respiration (C_{SIR})[34].

Total C in the K_2SO_4 extracts was determined using the Islam and Weil MW digestion method[35]. Microbial biomass C (C_{MB}) was calculated by subtracting C_{NMW} from C_{MW} and multiplying by an efficiency coefficient of $k = 0.21$ determined by Islam and Weil[32]. C_{AR} (a measure of reducing sugars) was determined by reacting 0.1% anthrone with 0.5 M K_2SO_4 extracts of MW sterilized field moist soil (C_{AR}) at 80°C in concentrated sulfuric acid[33] followed by spectrophotometric analysis of the resulting color complex. C_{SIR} was calculated as the difference in CO_2 evolution during a 6 h incubation of amended (glucose and nutrients) and unamended soil samples[34].

Soil (<2 mm) that had been dried overnight at 105°C was analyzed for (1) total C and N content using a dry combustion analyzer (LECO Corp., Warrendale, PA) and (2) particle size distribution using a modified pipette method[36].

Air dry soil (<2 mm) was analyzed for pH and Mehlich I extractable Mg, Ca, P and K using methods outlined by the Northeast Coordinating Committee on Soil Testing[37].

Air dry soil (1–4 mm) was analyzed for macroaggregate stability (AGSTAB) using a modified Kemper and Rosenau method[38]. AGSTAB was calculated as the mass fraction of <0.73 mm soil retained on a micro-sieve (50 mm diameter, 0.73 mm mesh openings) after rapid submergence in deionized water and 2 min of orbital shaking at 100 revolutions per minute.

The porosity of each soil was calculated assuming that all composite soil samples had a total volume of 380 cm^3 and a particle density of 2.65 $g\,cm^{-3}$.

Finally, two quotient parameters were calculated using the following functions:

$$qC_{MB} = C_{MB} * C_T^{-1} * 100 \quad (1)$$

$$qC_{NMW} = C_{NMW} * C_{MW}^{-1} * 100 \quad (2)$$

where C_{MB} is microbial biomass carbon, C_T is total C, C_{NMW} is extractable C from unmicrowaved soil and C_{MW} is extractable C from MW sterilized soil.

The parameters described above were determined for all soil samples with the exception of the routine soil test parameters (pH and Mehlich I extractable Ca, Mg, K and P) that were only measured for the first samples collected from each site and C_{SIR} that was only determined for samples collected during the spring and fall of 1997. Higher parameter values were assumed to indicate superior SQ for all parameters other than qC_{NMW} and clay content.

Calculating a SQI and three soil discrimination indices

A SQI was calculated by averaging normalized values of the five individual SQ parameters that best agreed with farmer SQ ratings. The component parameters were normalized around a mean value of 50 and a standard deviation of 10, using a Z score approach[39]. The following function was used to calculate the SQI:

$$SQI = \sum [(10 * \Delta p * p_{std}^{-1}) + 50] * n^{-1} \quad (3)$$

where Δp is the difference between the value of an individual component parameter and its data set mean, p_{std} is the data set standard deviation of the component parameter, and n is the total number of parameters integrated.

Discriminant analysis (DA) was used to generate three additional indices: (1) SDI_{TILL} with optimized discrimination between soils receiving conventional tillage management and no-till management, (2) SDI_{SOD} with optimized discrimination between soils under long-term sod and soils with no sod in rotation, and (3) SDI_{FR} with optimized discrimination between soils rated good and poor by farmers. DA was chosen over other multivariate statistical tools (e.g., principal component analysis) that are also useful for data reduction because DA is specifically designed for identifying minimum sets of variables that best discriminate between contrasting groups[39].

Parameters that best discriminated between the contrasting soil classes were identified using procedure PROC STEPDISC[39] with the stay criteria set at $p(F) < 0.05$. Paired classification functions of best discriminator parameters were calculated using procedure PROC DISCRIM[39]. The discrimination power of the calculated classification functions was tested using the resubstitution option in PROC DISCRIM[39].

Creating indices out of classification functions

The paired classification functions associated with the best discriminator parameters for each soil categorical contrast were combined by subtraction, forming single linear functions. The conventional tillage function was subtracted from the no-till function, the no-sod function from the long-term sod function and the poor rated soil function from the good rated soil function. Parameter values from the data sets were plugged back into the linear functions and SAS procedure PROC MEANS[39] was used to calculate data set means and standard deviations for the linear functions. The following function was used to calculate three indices (SDI_{TILL}, SDI_{SOD} and SDI_{FR}):

$$SDI = 10 * [f(x) - f(x)_{mean}] * f(x)_{std}^{-1} + 50 \quad (4)$$

where $f(x)$ is the linear function and $f(x)_{mean}$ and $f(x)_{std}$ are the mean and standard deviation of the linear function.

Evaluating the relationship between farmer SQ ratings and individual soil parameters

The relationship between individual soil parameters and farmer SQ ratings was evaluated using data associated with all samplings of all sites (75 soil SQ contrast pairs) and data associated with the first sampling of all sites (45 SQ contrast pairs). Paired t-tests (PROC MEANS[39]) were performed on Δp values ($\Delta p = parameter_{good\ rated\ soil} - parameter_{poor\ rated\ soil}$) to test the likelihood of parameters having Δp values greater than zero. Parameters with positive t-scores and $p(H_0) < 0.05$ were interpreted to be significantly in agreement with farmer SQ ratings. Mean percent parameter difference values were calculated for paired good and poor rated soils using the following function:

$$\text{mean percent parameter difference} = 100 * \sum (\Delta p * p_{mean}^{-1}) * n^{-1} \quad (5)$$

where Δp is the difference between the good and poor soil parameter values, p_{mean} is the mean parameter value for a pair of good and poor rated soils and n is the number of SQ contrast pairs. Parameters with greater mean percent difference values were interpreted to be more sensitive to farmer SQ ratings.

Evaluating the relationship between soil indices, index component parameters and farmer SQ ratings

Data associated with 48 paired sites sampled in spring and fall 1997 that had no missing values for component parameters, were selected for evaluating the relationship between the four calculated indices, individual component parameters and farmer SQ ratings. Paired t-tests (PROC MEANS[39]) were used to evaluate the relationship.

Table 3. SQ diagnostic indicators, best management practices for improving SQ, and the number of farmers that mentioned each ($n = 32$).

SQ indicators	Farmers	Management practice	Farmers
Soil organic matter content	28	Conservation tillage	26
Crop yield and appearance	22	Long-term no-till	16
Soil water availability	19	Sod in rotation	14
Minimum erosion/clear run-off	16	Manure/compost	11
Soil mineral fertility	14	Cover crops	9
Ease of tillage/soil density	10	Minimization of field traffic	6
Soil biological activity	9	Adequate liming	4

Results and Discussion

Diagnostic indicators of SQ mentioned by farmers

The indicators of SQ discussed by farmers during field interviews were ranked with respect to the number of farmers that mentioned each indicator (Table 3). Soil organic matter (SOM) was the indicator of SQ mentioned by the most farmers (88%). This high level of recognition of SOM as a SQ indicator concurs with Granatstein and Bezdicek[3] who stated that SOM is the most universally accepted indicator of SQ. Crop condition (e.g., yield, drought tolerance, pest damage and root appearance) was the next most frequently mentioned SQ indicator (69%). Farmers tend to have much more visual contact with their crops than their soils, and thus it is logical that many look to crop characteristics as SQ indicators. SOM and crop condition, the SQ indicators mentioned most frequently in this study, were also the top two indicators of SQ/soil health identified by Wisconsin farmers[11].

SQ indicators related to soil hydrologic function were mentioned by 59% of farmers. Four farmers commented that they consider soil water-holding capacity to be the most distinguishing feature between good and poor quality soils. Evidence of soil erosion was mentioned by 50% of farmers. Most of the farmers using minimum tillage practices mentioned that they have observed much less erosion on their farm as compared to their neighbors who use more intensive tillage practices or as compared to when they previously used more intensive tillage practices. The fact that a majority of farmers (63%) did *not* mention soil mineral fertility as a SQ indicator suggests many farmers perceive their soil productivity is currently not limited by soil mineral fertility. The relatively small fraction (31%) of farmers that mentioned ease of tillage is related to most (81%) of the participating farmers using minimum tillage or no-till systems. Soil biological indicators, such as the presence of earthworms and their middens, fungal fruiting bodies, rate of residue decay, etc., were mentioned relatively infrequently (28%) by farmers. This small percentage suggests a need for identification of practical biological indicators of SQ and training programs for mid-Atlantic farmers related to the importance of soil biology in mediating soil functions.

The percentages of farmers that described a relationship between SQ and specific soil and crop characteristics should not be interpreted as a direct measure of farmer valuation of the soil and crop characteristics as SQ indicators. Romig et al.[11] ranked SQ indicators based on a three part scoring system that assigned value based on when the indicator was mentioned in the interview, how frequently it was mentioned, and how many farmers mentioned the indicator. The less structured interviewing process used in this study necessitated a simpler and less inferential technique for quantifying interview responses. Direct insights into farmer valuation of specific SQ indicators can only be drawn from the individual farmer comments. Indicators described as most important by individual farmers included crop yield, soil water-holding capacity, crop root appearance, clarity of run-off, lack of soil compaction and ease of seed bed preparation.

Farmer perceptions of best management practices for SQ

Farmer remarks concerning the effects of specific management practices on SQ are summarized in Table 3. SQ benefits from minimizing tillage were described by 81% of the farmers. Among collaborating farmers, half have eliminated all tillage. This is congruent with the Conservation Tillage Information Center's[40] statistics for Maryland (50% of all crop acres were planted no-till in 1999). Many of the collaborating farmers that used no-till had not tilled for over 10 years and were convinced of the SQ benefits of long-term no-till. SQ benefits from including sod in crop rotations were described by 44% of the farmers. SQ benefits from the use of organic soil amendments (e.g., manure, compost) and cover crops were mentioned by approximately one-third of the farmers (34 and 28%, respectively); however, the farmers that mentioned these practices were very convinced of their positive impact on SQ. In addition to describing positive management effects on SQ, many farmers, particularly those using continuous no-till, described the negative impacts of excessive field traffic, any traffic over wet soils, inadequate liming and application of pesticides that are toxic to earthworms.

Table 4. Significant relationships between farmer SQ ratings and soil parameters associated with all samplings of paired SQ contrast sites.

Parameter[1]	*n*	Units	Good rated soil mean	Poor rated soil mean	Mean percent difference	Paired *t*-test: $p(H_0)$
C_T	74	$mg\,g^{-1}$	18.6	15.2	14.1	<0.0001
C_{MB}	75	$mg\,g^{-1}$	0.563	0.398	29.4	<0.0001
C_{MW}	75	$mg\,g^{-1}$	0.203	0.151	21.3	<0.0001
C_{NMW}	75	$mg\,g^{-1}$	0.085	0.068	14.8	0.0005
C_{AR}	75	$mg\,g^{-1}$	0.088	0.067	19.9	<0.0001
qC_{MB}	74	%	3.06	2.57	15.7	0.0071
qC_{NMW}	75	%	43.3	48.4	−6.4	0.0058
AGSTAB	70	%	51.4	38.3	26.3	<0.0001
Porosity	75	%	51.2	49.4	2.6	0.0003
θ_m	75	%	26.1	23.7	6.1	0.0344

[1] C_T = total C, C_{MB} = microbial biomass C, C_{MW} = C in 0.5 M K_2SO_4 extract of MW irradiated soil, C_{NMW} = C in 0.5 M K_2SO_4 extract of non-irradiated soil, C_{AR} = anthrone reactive C in 0.5 M K_2SO_4 extract of MW irradiated soil, C_{SIR} = substrate induced respiration rate, $qC_{MB} = C_{MB}\,C_T^{-1}$, $qC_{NMW} = C_{NMW}\,C_{MW}^{-1}$, AGSTAB = % macroaggregate stability, θ_m = gravimetric moisture content at sampling.

Table 5. The relationship between farmer SQ ratings and soil parameters associated with the first sampling of paired SQ contrast sites.

Parameter[1]	*n*	Units	Good rated soil mean	Poor rated soil mean	Paired *t*-test: $p(H_0)$
C_T	44	$mg\,g^{-1}$	17.6	14.6	0.0075
C_{MB}	45	$mg\,g^{-1}$	0.486	0.342	0.0002
C_{MW}	45	$mg\,g^{-1}$	0.189	0.141	<0.0001
C_{NMW}	45	$mg\,g^{-1}$	0.087	0.070	0.0230
C_{AR}	45	$mg\,g^{-1}$	0.078	0.059	0.0002
AGSTAB	41	%	52.4	38.2	0.0015
Porosity	45	%	46.7	44.3	0.0010
pH	41	−log(H)	6.5	6.3	0.0570
Ca	40	$mg\,kg^{-1}$	1182	989	0.0630
Mg	36	$mg\,kg^{-1}$	152	140	0.0280
Ca : Mg ratio	36	na	4.9	4.2	0.1340
K	39	$mg\,kg^{-1}$	190	182	0.6390
P	41	$mg\,kg^{-1}$	184	154	0.0910
Sand	35	%	45.0	42.4	0.0460
Clay	35	%	10.5	12.1	0.0158

[1] Ca = Mehlich I extractable calcium, Mg = Mehlich I extractable magnesium, Ca : Mg ratio = equivalents Mehlich I extractable Ca * (equivalents Mehlich I extractable Mg)$^{-1}$, K = Mehlich I extractable K_2O, P = Mehlich I extractable P_2O_5, sand = % sand, clay = % clay; see Table 4 for additional parameter abbreviation interpretations.

SQ parameters

SQ parameter statistics for all samplings are presented in Table 4. Statistics for just the first sampling of each site are presented in Table 5. Select statistics for samples collected in the spring and fall of 1997 are presented in Table 8.

Soil C parameters (C_T, C_{MB}, C_{MW}, C_{AR} and C_{SIR}) and soil structure parameters (porosity and AGSTAB) were found to agree well with farmer SQ ratings ($P < 0.0005$). Quotient parameters qC_{MB} and qC_{NMW} also had a highly significant level of agreement with farmer SQ ratings ($P < 0.007$). Sparling[41] suggested that active C:total C quotients have greater meaning than absolute active C levels when comparing soils with differences in texture, drainage, or climate, and therefore different inherent capacities to retain SOM. When comparing soils with similar inherent properties, such as in this study, quotient parameters would not be expected to have an advantage.

For a parameter to be useful as a SQ indicator, the parameter should consistently (i.e., with a high probability) differ between good and poor quality soils and the difference should be relatively large in magnitude so as to be readily detectable. Many authors[23,24,42] have reported that soils with contrasting management have greater relative differences between biologically active C parameters as compared to total C. This study found that soil C parameters associated with MW sterilized soil (C_{MB}, C_{MW}, C_{AR}) had mean percent differences (29.4, 21.3 and 19.9%, respectively) that were larger than those associated with C_T and C_{NMW} (14.1 and 14.8%, respectively) (Table 4).

Table 6. Soil parameters identified using SAS procedure PROC STEPDISC as the best discriminators between tillage, presence of sod and farmer rating soil categories

Contrast	Parameters[1]	Partial R^2	p(F)
Tillage intensity	AGSTAB	27.5	0.0001
	qC_{NMW}	10.9	0.0007
	Porosity	7.07	0.0072
Presence of sod	C_{MB}	26.11	0.0001
	AGSTAB	13.65	0.0001
Farmer soil rating	C_{NMW}	6.2	0.0082
	C_{SIR}	4.9	0.0199

[1] See Table 4 for parameter abbreviation interpretations.

Experimental error is unlikely to obscure the relationship between a particular parameter and farmer SQ ratings if the differences in parameter values between good and poor rated soils are many times greater than the coefficient of variation (CV) for the analytical method. Among the parameters measured in this study, the ratio of mean percent difference to CV was greatest for C_{MW}, C_{AR} and AGSTAB (14.2, 7.7 and 3.7, respectively), indicating that these three parameters may be most reliable in distinguishing between soils with contrasting SQ. Islam and Weil[43] found these parameters to be among the best discriminators between soils managed with and without conservation practices.

At the first sampling of each pair of SQ contrast sites, soils were analyzed for all the soil parameters just discussed as well as particle size distribution and standard mineral fertility parameters (Table 5). AGSTAB and all the soil C parameters agreed well ($P \ll 0.05$) with farmer SQ ratings. Mehlich I extractable Mg was the only mineral fertility that differed significantly ($P < 0.05$) between good and poor rated soils. The Ca : Mg ratio, a relationship considered important by proponents of the base cation saturation ratio (BCSR) approach to soil fertility management[44], was not significantly related to farmer SQ ratings.

Both sand and clay showed small but statistically significant ($P < 0.05$) differences between paired sites. Good rated soils had $16\,mg\,g^{-1}$ less clay and $26\,mg\,g^{-1}$ more sand than poor rated soils. This difference in texture, for soils mapped as the same or very similar soil series, is likely to relate to differences in erosion. Compared to less eroded sites, more eroded sites would have clay-enriched argillic horizons closer to the surface and more likely to be incorporated into the Ap horizon by tillage. In addition, erosion tends to enrich surface soil with clay by preferentially removing fine sand and silt-size particles[45]. It is also possible that some of the measured textural differences were related to incomplete dispersion of microaggregates during particle size analysis[46].

Development of indices from linear classification functions

The parameters identified as the best discriminators (by stepwise DA) between tillage classes, presence of sod classes and farmer SQ rating classes are presented in Table 6. Parameters AGSTAB and C_{MB} were associated with greater than 25% of the variability between tillage and presence of sod classes, respectively. None of the individual parameters were strong discriminators between the unpaired good and poor rated soil populations (Table 6). The normalized linear combinations of best discriminator parameters used to calculate SDI_{TILL}, SDI_{SOD} and SDI_{FR} were as follows:

$$SDI_{TILL} = 0.310 * AGSTAB - 0.357 * qC_{NMW} - 0.695 * \text{porosity} + 91.15$$

$$SDI_{SOD} = 18.22 * C_{MB} + 0.197 * \text{AGSTAB} + 33.9$$

$$SDI_{FR} = 263.9 * C_{NMW} + 11.03 * C_{SIR} + 23.39$$

Using the resubstitution option in SAS procedure PROC DISCRIM[36], we compared the discrimination power of a linear function of all measured parameters with a function of the best discrimination parameters. The respective classification success rates for these two types of functions were: 85.3 versus 82.4% for conventional tillage: 83.1 versus 83.1% for no-till, 86.5 versus 86.5% for no-sod, 83.3 versus 75.0% for sod, 65.5 versus 62.1% for good rated soils and 87.0 versus 66.7% for poor rated soils. Thus, functions comprised of only two or three best discriminator parameters were nearly as good at discriminating between the contrasting soil categories as functions containing all measured parameters.

Relationships between SQ ratings by farmers and indices and index component parameters

Means and standard deviations of the component parameters are presented in Table 7. Paired *t*-test, *t*-scores, and $p(H_0)$ values associated with indices and index component parameters are presented in Table 8. Unlike Tables 4 and 5, all the parameters presented in Table 8 are associated with the same number of SQ contrast pairs ($n = 48$). As a result, it is meaningful to compare *t*-scores in addition to $p(H_0)$ values.

The SQI that integrated the five best individual parameters (based on data from all samples) had a *t*-score of 7.52. The five best individual parameters (C_T, C_{MW}, C_{MB}, C_{AR}, AGSTAB) had *t*-scores ranging from 4.63 to 6.71. This demonstrates that linear combinations of SQ parameters can be assembled which are more in agreement with holistic SQ criteria such as farmer SQ ratings than individual SQ parameters. The process of averaging multiple parameters, which was used in creating the SQI, reduced the impact of individual parameter variability. We speculate that this statistical process is analogous to the process by which farmers make their judgments of SQ. For example, single observations of erosion, drought stress or pest damage are unlikely to cause a farmer to rate a site as having poor SQ if the farmer's overall recollection of soil performance at the site is favorable.

DA using appropriate class contrasts produced linear combinations of soil parameters that were strongly related

Table 7. Data set parameter means and standard deviations used in the calculation of the soil indices: SQI, SDI_{TILL}, SDI_{SOD} and SDI_{FR}.

Index	Parameter	Category	*n*	Mean	Standard deviation
SQI[1]	C_T	–	256	16.2	7.1
SQI	C_{MB}	–	285	0.405	0.27
SQI	C_{MW}	–	287	0.146	0.078
SQI	C_{AR}	–	281	0.070	0.051
SQI	AGSTAB	–	263	45.3	26.7
SDI_{TILL}	AGSTAB	NT	71	49.0	26.0
SDI_{TILL}	AGSTAB	CT[2]	34	18.7	16.7
SDI_{TILL}	qC_{NMW}	NT	71	44.5	15.7
SDI_{TILL}	qC_{NMW}	CT	34	55.8	19.6
SDI_{TILL}	Porosity	NT	71	51.9	5.8
SDI_{TILL}	Porosity	CT	34	52.1	6.1
SDI_{SOD}	C_{MB}	LS	24	0.790	0.541
SDI_{SOD}	C_{MB}	NS	111	0.336	0.209
SDI_{SOD}	AGSTAB	LS	24	74.1	24.9
SDI_{SOD}	AGSTAB	NS	111	36.5	25.5
SDI_{FR}	C_{NMW}	RG	58	0.069	0.031
SDI_{FR}	C_{NMW}	RP	54	0.054	0.025
SDI_{FR}	C_{SIR}[3]	RG	58	1.060	0.643
SDI_{FR}	C_{SIR}	RP	54	0.810	0.502

[1] SQI = *f*(C_T, C_{MW}, C_{MB}, C_{AR}, AGSTAB), SDI_{TILL} = *f*(AGSTAB, qC_{NMW}, porosity), SDI_{SOD} = *f*(C_{MB}, AGSTAB), SDI_{FR} = *f*(C_{NMW}, C_{SIR}).
[2] CT = conventional tillage, NT = no-till, LS = long-term sod, NS = no sod in rotation, RG = rated good quality by farmer, RP = rated poor quality by farmer.
[3] C_{SIR} = substrate induced respiration rate in μmol CO_2 $(g\ soil)^{-1}\ h^{-1}$. This parameter was not included in previous tables because it was not analyzed during the initial sampling season. See Tables 4 and 5 for all other parameter abbreviation interpretations and units.

to farmer SQ ratings. The index derived from contrasting long-term sod and no sod in rotation (SDI_{SOD}) had the strongest level of agreement with farmer SQ ratings of the three indices. This is not surprising as the positive impact of sod on SQ has been described by many authors[47–49].

The index based on farmer ratings (SDI_{FR}) was calculated as a linear function of two parameters, C_{NMW} and C_{SIR}, which were selected because they optimized discrimination between *unpaired* good and poor rated soils. Individual parameters (C_T, C_{MW}, C_{NMW}, C_{MB}, C_{AR}, C_{SIR} and AGSTAB) that were analyzed for within-pair differences were more in agreement with farmer SQ ratings than SDI_{FR}, as indicated by lower $p(H_0)$ values. The greater level of agreement associated with paired analysis as compared to unpaired analysis demonstrates a major SQ research challenge. Many soil parameters that are good discriminators between sites that have received contrasting management but have similar inherent soil properties do not appear to have absolute threshold values that would allow SQ assessment across soils that differ widely in their inherent properties.

Table 8. Results of paired *t*-tests between contrasting SQ sites for soil indices and individual component parameters ($n = 48$ pairs).

Parameter[1]	*t*-score	$p(H_0)$
C_T	5.84	< 0.0001
C_{MW}	6.71	< 0.0001
C_{NMW}	4.94	< 0.0001
C_{MB}	5.61	< 0.0001
C_{AR}	5.56	< 0.0001
C_{SIR}	3.94	0.0003
qC_{NMW}	−2.11	0.0399
AGSTAB	4.63	< 0.0001
Porosity	2.14	0.0379
SQI	7.52	< 0.0001
SDI_{TILL}	3.45	0.0012
SDI_{SOD}	6.76	< 0.0001
SDI_{FR}	6.08	< 0.0001

[1] See Tables 4 and 7 for parameter abbreviations.

The index based on contrasting tillage regimes (SDI_{TILL}) had the weakest relationship with farmer SQ ratings of the three soil discrimination indices. This is not surprising as only six of the 48 SQ contrast pairs consisted of a good rated soil receiving less intensive tillage management than its poor rated pair. In fact, both the good and poor rated soils in 15 out the 48 SQ contrast pairs were under NT management. The inclusion in the index database of 15 soils under no-till management that had been described as poor quality by their farmers, reduced the strength of relationship between SDI_{TILL} and farmer SQ ratings.

Conclusions

Farmer knowledge of SQ as encapsulated in contrasting SQ ratings assigned to paired sites provided a useful benchmark for evaluating the relationship between management-sensitive soil parameters and SQ. Among the individual SQ parameters measured, C_{MW} had the highest level of agreement with farmer SQ ratings as indicated by low $p(H_0)$ and high mean percent difference values. This parameter is closely related to microbial biomass, and several authors[50,51] have suggested that biomass C can be estimated without subtracting a control (C_{NMW} in this study). AGSTAB and soil C parameters (C_T, C_{MB}, C_{AR}, C_{SIR}) also agreed well with farmer SQ ratings. Some of the quotient parameters investigated (qC_{MB} and qC_{NMW}) did not agree as well with farmer SQ ratings as their component parameters.

The calculated SQI had the highest *t*-score of all measured and calculated parameters (associated with samples collected in the spring and fall of 1997 that had no missing values) demonstrating that linear combinations of SQ parameters can be assembled which are more in agreement with holistic SQ criteria such as farmer SQ ratings than individual SQ parameters. DA was an effective approach for selecting and integrating minimum data sets of SQ parameters into discrimination indices that are related

to farmer perceptions of SQ. This objective method of data reduction based on ability to discriminate between soils with contrasting management merits more investigation.

The lack of differences in pH and available nutrients between soils rated by farmers as having contrasting SQ, suggests that these mid-Atlantic farmers have largely resolved mineral fertility constraints on SQ. In contrast, parameters related to soil structure and C were found to be strongly related to SQ ratings by these mid-Atlantic farmers. This suggests that efforts to improve SQ in the Mid-Atlantic region should focus on monitoring and enhancement of soil C and soil structure.

The integration of on-farm data as collected in this study with data from appropriate replicated experiments may allow the identification of threshold values for select SQ parameters and thus move SQ interpretation beyond relative comparisons of soils with similar inherent properties.

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Work: A necessary sacrifice or a suffered chore? Labor and farm continuity in alternative agriculture in France

Catherine Macombe[1,2,*]

[1]CEMAGREF, UMR Métafort, 24 avenue des Landais, BP 50085, 63 172 Aubière cedex, France.
[2]GREGOR-Institut d'Administration des Entreprises, Paris I, Panthéon-Sorbonne.
*Corresponding author: catherine.macombe@cemagref.fr

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Abstract

Systems advocating alternative agriculture would appear to be handicapped by the amount and the minutiae of human labor required. Is this really a threat to the continuity of farms associated with these systems? We do not believe that this directly hampers the survival of a farm. We advance the theory that continuity is not just down to chance; the farmer at the time chooses to prolong the life of the farm and more especially to look for a successor. We have shown through a study conducted in central France (Auvergne) that the main guarantee of organizational sustainability, that which sustains the business as a viable entity when another person takes over, is when a farmer thinks of his farm as an entity-cum-project supporting a meaningful life plan. A farmer might also see his farm solely as capital or as heritage, but neither of these last two attitudes is sufficient for him to ensure the spirit of his enterprise is passed on. There is a particularly large number of farmers in the first category (entity-cum-project) who adopt alternative farming practices, which are meaningful. It also seems to be the case that the manner of working is closely linked to the moral principles of farmers who use alternative systems. Moreover, the same objective amount of work that might be thought excessive in a system that puts strong emphasis on high productivity, is regarded as normal in an alternative system. Farmers often approach extension advisors to help reorganize their working conditions. We maintain that alternative systems have peculiarities with regard to work that make this type of advice difficult. Our aim is to help advisors clearly construct the input they give to the various types of farmers. We put forward a typology of possible practices as regards advice on work, according to assessments farmers have made about the amount of work they do and their way of working. The large number of hours devoted to an alternative farming activity and the nature of that activity, whether demanding or linked to practices thought archaic, are not always a handicap to the continuity of an alternative system. On the contrary, these features can be its hallmark.

Key words: work/labor, alternative agriculture, continuity, sustainability, advice, ethics

Introduction

In Western countries, successive green revolutions have replaced energy provided by human labor with that of animals and then with various natural sources (the sun, wind and water) and lastly with fossil fuels[1,2]. Today, the agricultural model that is predominant in the West puts strong emphasis on high productivity[3] that cuts down on human labor as much as possible. Farms of this type apply a strategy of low-cost leadership[4], which includes reducing labor costs to a minimum. In contrast, all the Western systems of alternative agriculture, according to Michael Porter's terminology, seek differentiation where the products sold must be perceived by customers as being different from standard products, rather than low-cost leadership. From a labor point of view, alternative agriculture systems might then appear to be a backward step. Adopting an alternative system actually involves more human labor[5]. Results of the farm census in 2000, in France, show that heads of organic farms work full time in most cases and that they have 2.8 employees compared to 2.3 in other farms. But do these work requirements really put a brake on adoption? Other curbs are confirmed: regarding organic farming for example, Gautronneau[6] showed that a major obstacle to adoption in France was a fear of being marginalized, while a recent study[7], carried

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out in California, proved the influence of management styles on adoption. Is the adoption of alternative agriculture systems hampered in Western countries, where everyone can make comparisons with the conditions in the productivity-driven farming system by the amount and nature of the work involved? More generally, is the work a threat for continuity of these alternative systems? Research based on 30 case studies conducted in Auvergne, a medium-sized mountain region in central France, may provide fuel for this debate. The exercise involves examining the complex relation between work and continuity and drawing lessons from that to help farms that specialize in alternative agriculture.

In France, farmers often approach extension advisors in connection with work[8] and yet alternative systems have peculiarities with regard to work that make such advice difficult. Our aim is to help advisors construct the input they give to the various types of farmers. We put forward a typology of possible practices as regards advice on work, according to the assessments farmers made about the amount of work they do and their manner of working. The advice needs to be different depending on the particular type of farmer who is using or is considering using an alternative agriculture system.

The Paradoxes of Work and Continuity

Might bad working conditions be a threat to the continuity of alternative farms? It stands to reason that too high a workload threatens the sustainability of a farm and yet this is not automatic. Proper working conditions are not a guarantee of continuity either; for instance, there are many cases where farmers have a modest workload but still do not manage to perpetuate their farm. On the other hand, there are farms weighed down by a huge workload but this in no way hinders their continuity. This fact is illustrated by the following case:

> In 2002, Mr and Mrs R4 found a couple of young people to take over their vineyard run using organic farming methods, even though it requires a huge amount of work. For instance, they considered it normal to work on Sunday as well: "*Well, since we've reduced by a hectare, we've managed to stop working on Sunday afternoon.*"

The same observation can be made about archaic practices.

> In Auvergne for example, it was assumed that the milking of Salers cows had disappeared because the physiology of this breed is such that, for the mother to release her milk, she has to be in contact with the calf that must suck the first spurts. This practice would have been doomed because of the extra work it entailed and yet the survival of Mr C's farm, which is devoted to milking Salers cows, is in no way threatened: he has recently formed a farmers' economic interest group, or GAEC as it is known in French, with his wife and one of his employees. His two children are planning to take over the farm. As far as the milking is concerned, this is certainly a constraint but it is not an insuperable obstacle: "*The system is like that. It calls for employees, so it takes two of us to do the milking, one who milks and the other who lets the calves out, so you need a herd that's a tiny bit bigger to be able to hire two people. To pay the contributions and the wages*".

If we adhere to the line that 'good' working conditions are essential to the continuity of a farm, these paradoxes cannot be explained. But it is not that simple; every practitioner knows that the expression 'good working conditions objectively defined' is meaningless: faced with the same herd and put in the same situation, one farmer will cope with no problem while his neighbor will be snowed under. Only the farmer himself can say whether the working conditions are 'good' or 'bad'.

In France there are two main ways to tackle the description of work on farms. The first is known as 'administrative' and is a learned description put forward by agriculturists[9]. It is objectivist and macroscopic[10]. There are two variants according to Dedieu et al.[11], the first favors breaking down tasks and measuring their duration; the second aims to show the work in the form of budgets worked out per period (taking stock of time available and needs). The second approach, described as 'subjective' by Dejours[10], is comprehensive and intersubjective because it is formed from the experience that the operators themselves have of work. Our approach belongs to this category, since the reflections on 'work' that we put forward are always to be understood as being 'the farmer's assessment of the issue'. This is one of the first keys to gaining an understanding of these paradoxes. The farmer is the one who has to assess whether the amount of work he undertakes is bearable or not and it is he again who gives purpose, or not, to his way of working. However, the debate cannot get off the ground without clarification of the term 'farm continuity'.

Up until 1995[12] around 70% of French farmers were getting one of their children to take over from them. The number of farmers is falling and those who remain have fewer and fewer children who want to take over a farm, with the result that the use of successors chosen from outside the family circle could possibly grow[13], although this runs counter to the French tradition of passing on a farm to a relative or, where none exists, of selling the land for development or planting it with trees. What does 'farm continuity' actually mean when someone takes over? It is necessary to draw upon the work done by Sophie Mignon[14] on companies in general. This author identifies four main modes of continuity when a succession takes place: two concerning continuity of power and two concerning continuity of project.

Table 1. Source of the names that make up the list of 70 farmers.

- The names of farmers featured on the Thursday 'Country life' page in the local regional newspaper, *La Montagne*, in 2000 (novel agricultural experiments, integrated pest management, etc.)
- The names of prizewinners at agricultural shows for cattle and sheep breeds (Paris Agricultural Show, 2000).
- The names of breeders featured in the book *Montagnes à vaches, vaches de montagne* published by 'France Agricole', 2000 (extensive livestock rearing systems in mountain areas).
- The names of breeders of endangered domestic breeds published in advertisements in the journal *Ferme* in 2000 (systems farming local breeds).
- The names of farmers mentioned in issue 38 of *Massif Central Magazine*, 2000.
- The names of farmers taken from the leaflet, 'La route des métiers', published by the Parc Naturel Régional du Livradois Forez for 2001 (a wide range of farmers using organic farming methods).
- The names mentioned in CIVAM's leaflet, 'L'Auvergne de ferme en ferme', published for farm visits in April 2000 (a wide range of farmers using organic farming methods).

FERME: Fédération européenne de revalorisation des races domestiques menacées (Association for the Promotion of Endangered Domestic Breeds). The addresses are rarely those of farmers because more often than not they concern spare time breeders.
CIVAM: Centre d'Initiative pour la VAlorisation du Milieu rural, not-for-profit association taking over from the 'rural teachers' of old.

In farming, continuity of power is conveyed either by continued *control* when the capital stays in the hands of the same family, or by continued *management*, when successive farmers belong to the same family.

The other major type of continuity—continuity of project—is broken down into sustainability of the *activities* and of the *organization*. Sustainability of the *activities* is ensured when the farm activities continue, even when the founding family has lost control of them. *Organizational* sustainability is a subtler notion. It occurs through maintenance of the 'spirit of the business', which guarantees its singularity and its unity, or by keeping its identity[15]. Edith Penrose defines identity as the basic, permanent character of a group which lasts in spite of change[16]. This form of sustainability is the one that alternative systems are interested in. Sustainability of these systems is dependent on the handing down of their 'spirit', of their own alternative identity.

To identify the conditions of this last form of continuity, we carried out research (2000/2002), based on 30 case studies of farmers in Auvergne, which focused on the farmer's work ethic to explain the intended continuity of the farm. This research gave rise to a management science dissertation defense[17]. The specific goals were double. First, we wanted to understand why some farms were passed on and others not, in order to suggest advice for extension and training. Secondly, according to the field of management science, the dissertation hoped to make a contribution to managers' strategy. We therefore noted the conditions to extend these results to farms and, more generally, managers of small family firms, in developed Western countries, as per Albert David's method[18].

Methodology

Data collection techniques

A selective sample had to be gathered to reveal a phenomenon that is, in principle, relatively rare. We were looking for people who might have something to say about the notion of quality. We therefore put together a list of 70 farmers working with alternative agriculture systems in the Auvergne region using seven media sources (Table 1).

We chose a varied sample[19] from this base according to known features (agronomic potential, main activity, tourist activities or none, type of marketing, production method, legal structure). Table 2 below examines the diversity criteria sought.

Appointments were made by telephone during the school holidays as follows: summer 2000, Christmas 2000/2001, February 2001 and summer 2001. The 30 interviews took place on the farms and were recorded for transcription. According to standard recommendations[20], visual impressions of the following elements were gathered: interview venue, the surroundings, interruptions during the interview, what the farmer wanted to show, what is important to him, visible equipment, buildings and lastly state of the land, crops and animals.

The utmost was done[21] to put the interviewees at ease, so that they could express themselves freely. The two main subjects for the interviews had no relationship, in principle, with work. They were asked: 'What, in your opinion, does the quality of farm produce mean?' and then, if they did not broach the question themselves, 'What future are you hoping for and what future are you planning for your farm'. The interviews were conducted according to the non-directive-active technique described by Mucchielli[22]. The remarks about work recorded here were therefore produced spontaneously, without any specific question being asked on that subject. Analysis of the reflections on work was achieved by the grounded theory method[23], which helps draw out new theories.

Evaluating the type of continuity sought

We did not select farms in the process of handover. We interviewed employers of all ages. A criterion was needed to detect whether the farmer wanted 'organizational

Table 2. Diversity criteria sought among farms in the selected sample, in comparison with the ones sought by Sophie Mignon[14].

For SMEs (Sophie Mignon)	For farms in Auvergne
Sectors	Conveyed by main farm activity sector (**livestock breeding**, field crops, market gardening, off-ground cultivation, services)
Types of activity	Different farm production in the same **sector** (beef cattle, milk, sheep, goats for breeding, etc.) and **managed** in different ways (organic farming or not, etc.)
Size strata	Family farms but governed by various **legal forms** and with one or more associate **farmers**. With or without **employee**(s)
Nature of markets	Selling by cooperative, grouping, selling direct at market, by mail order, with or without AOC/PDO (Appellation Origine Contrôlée/Protected Designation of Origin). Farmer only or farmer with another job Age and gender of farmer

Table 3. Types of continuity looked for in relation to the way the farm is represented.

Whether the farmer first regards the farm as:	The first thing he/she wants for the future of the farm is:					
	Continuity of power		Continuity of project			
	Control	Management	Activities	Organization	No continuity	Examples
Capital	No	No	No	No	Yes	Farm sold to someone outside the family, or planted with trees or sold by lots.
Heritage	No	Yes	Yes	Yes or no	No	Handed down to a child or to a person chosen from outside the family circle but accepted.
Entity-cum-project	No	No	Yes	Yes	No	The spirit is passed on to the new farmer.

sustainability'. We assumed that, if this were the case, the farmer would refer to his business as an entity-cum-project[17]. This is one of three possible representations. Each farmer regards his farm as representing either capital or heritage or an entity-cum-project. Table 3 shows the logical coherence between these three representations and the types of continuity looked for.

The expression 'regarded as capital' means that the farm is seen first and foremost as an asset to be realized in monetary terms. It can be 'transformed' into a forest or plots. It also disappears as an entity if the farmer sells the business without passing on the particular expertise that forms its identity. In this case, the farmer is not concerned about preserving identity because organizational sustainability does not matter much to him.

If the farmer regards the farm primarily as heritage, it is important to *pass on* not only the tangible assets, but also a series of *intangible elements* that are meaningful to him, for example love of the land, the area, know-how, cultural heritage, etc. In this case, he often wants the children to take over the farm. He considers that it is important to carry on the same activities and also to keep the 'spirit' of the enterprise.

The farmer who considers he is at the head of an entity-cum-project sees his resources as the means to fulfill his ambitions. This viewpoint contributes to subtle organizational sustainability. The important thing is that *the identity of the farm lives on*. So the farmer frequently anticipates that the person taking over can produce other things, provided that is done in 'the same spirit'.

Each representation is linked to characteristic statements. For example, a farmer regards his farm as an entity-cum-project when he says, at an altitude of 1200 m in the Sancy Massif: '*If a **system** isn't sustained, whether by the children or by someone else—that's not important—it's proof that it just no longer had its place*'. Or indeed: '*We are doing everything possible precisely to create something that can be taken over easily, because this here is **a real creation***'. Conversely, the farm is repudiated as a project by the people who maintain: '*When you look at the life in towns, it'll be very difficult to get people to come here to do this job, just now we feel that people don't want to work 70 hours a day to do this job.*' or '*My son's doing quite different studies, ... I don't know if I'm not going to think of stopping anyway, just because of a problem of organisation, of too much work.*

This interpretation table gives a precise idea of the continuity the farmer wants.

Results and Repercussions for the Work Issue

Main result

In our sample, 23 farmers wanted above all to pass on the spirit of their business. The main result of our study is that these farmers have a genuine work ethic[24], assessed according to precise criteria. We tried to apply the most varied and most extreme situations possible in an attempt to disprove this proposition but it stood firm. In other words, if we extend these results, the fact that the farmer has a work ethic would seem to be a deciding factor in his alternative system being sustained. In such a case, the business is underpinned by a spirit and a purpose and the farmer does everything possible to preserve it beyond the end of his working life. He will actively look for a successor if he does not have any children who want to take it over. And above all, he will actively seek to pass on the spirit of the business. These results shed light on the paradoxes seen with regard to work. The manner of working is one of the principles that underpin the work ethic of these farmers, whereas it is not particularly meaningful for the other farmers. Similarly, the extra amount of work does not have the same consequences on the continuity of an 'entity-cum-project' as on the continuity of the other farm types.

Relationships between continuity and 'way of working'

When a farmer has a work ethic, the 'work' itself is part of the principle. In this case the word 'work' is used in the etymological sense reflecting a time when labor, which was 'neither counted nor measured', 'used to take shape in the product' as Barthez[25] wrote. So, 'work' refers to the ways of working to obtain a product and takes shape in this product, which owes it its worth. When a farmer has a work ethic, his way of working, and particularly some of the requirements he sets himself, take on a special meaning. For instance, a way of working that others might consider hard is regarded as a necessary sacrifice for the quality of the products obtained. It is part of the principle that gives purpose to the job, as the following passage shows:

> Mr O (herd of 55 Montbéliard cows): "*We don't have a milking parlour and we've got quality, we always have milk that's an A in quality. It's far more demanding than a milking parlour, and I won't say that we won't adopt it one day but we can monitor the animals, we are in contact with them, but that's a breeder's attitude, our animals are much more docile...*".

Conversely, when a farmer does not regard his farm as a project, the way of working does not have any particular significance. It will be a case of doing things as efficiently as possible, or indeed as quickly as possible:

> "*The guys who are chasing after acres and subsidies they don't care, they'll look at the big tractor ... that's going to do the work as quickly as possible, because there's 150 hectares of hay to do and it's got to be done quick*".

In other words, when a farmer has a work ethic, an outside observer could consider his way of working to be strange or archaic, but it often reflects the way he sees the job and is the hallmark of this way of seeing things, which actually leads to continuity.

Relationships between continuity and amount of work

The second approach involves the amount of work. When a farmer only sees his farm as capital, large amounts of work will be considered excessive. His work is a chore to be suffered and is hard to come to terms with. He therefore tries to reduce his working time by any means:

> "*Mr K: That [label requirements] is great on paper but in terms of work it's awful. We handle tons of lambs, it's horrible.*
> *Mrs K: It's cottage industry on a big scale, we say that all the time. We work traditionally while trying to produce industrial quantities*".

If a farmer sees his farm as an entity-cum-project, his position is different. He accepts that huge quantities of work are inherent to his way of running the alternative activities he has chosen. But he may realize that the amount of work he has no problem putting up with will never be acceptable to a potential successor:

> "*Mrs R: Because before getting to the end there's a huge amount of work to do, work in the fields, afterwards work by hand" ... "nobody's interested. We had a trainee at the beginning who was really interested, but when he saw the work that was involved ...*."

The result is that the farmer may like to pass on the entity, but she admits that it will be hard. On the other hand, the aim to work 'well' is in active opposition to the aim not to work a lot, both for activities requiring a huge amount of processing and for field crops, for example.

> (Mrs T) "*If we want a good, clean snail, that means a huge amount of work, taking a long time. I only do 3,000 in a day. I can't do any more, that for me is a quality snail!*"
> (Mrs U) "*The processing really does give a lot of work when you want to make a quality product, it takes time to make it...because we only use fresh products ... you need garlic and onions and to peel all that.*"

Table 4. Typology of farmers according to the opinions given on the amount of work and the way of working.

	Amount of work	
Way of working	**Thought normal**	**Thought excessive**
Has a particular significance The farm is an entity-cum-project	The project dictates the way of working. The resultant amount of work is a necessary sacrifice, it is thought normal. Organizational sustainability is hoped for and predicted. (Example of T)	The project dictates the way of working, but the resultant amount of work is thought excessive. It is hoped the farm will continue but not predicted as such. (Example of R)
Has no particular significance The farm is not an entity-cum-project	The amount of work is thought normal. The way of working has no particular significance because there is no specific work ethic. Continuity of power may be sought.	Work is a suffered chore. The way of working has no particular significance and there is no ambition to continue the farm. (Example of K)

(Mr P) "*Well, for example, to control corn borer, the trichogram is a parasite that is placed at the bottom of small capsules where there are larvae inside and we put them in the maize, in a little box, we place them by hand, so that means extra work.*"

(Mr and Mrs M) "*What you find in shops is onion seedling, it's very hard so it can be 100% machine processed! Ours is onion bulb and it's more fragile, so we pick it by hand too. It's a question of quality.*"

The result is that farmers with a work ethic consider an amount of work that would be deemed intolerable elsewhere to be 'normal'. This long work period in comparison with the unit produced is willingly accepted because it contributes to the purpose of the farmer's alternative project.

Implications for Advice

Typology and interpretation of the paradoxes

What becomes of our paradoxes in the light of the explanations given? The first case showed a couple of winegrowers using organic farming methods who were able to find successors, despite the huge amounts of work to be put in. But the amount of work was considered normal, because it was linked to a fundamental choice of an organically grown product. They related their meaningful way of working with the need for an amount of work which others might have considered excessive. As they wanted to sustain this 'organically grown' spirit, it is not surprising that they successfully brought a handover to fruition. The second case showed a way of working (milking Salers cows) which is generally considered to be archaic and doomed to disappear and yet the farmers organized themselves to take on the work and to pay for it by selling the cheeses for a high price at market. The archaic milking process is an integral part of their work ethic, itself at the root of their desire for the entity-cum-project to last.

We can thus put forward a typology of the farmers' attitudes to work and to the continuity of their farm (Table 4).

A farmer who is at the head of an entity-cum-project and who considers his amount of work to be 'normal' accepts that this workload is the sacrifice needed for his practices to match his work ethic. He hopes to pass on the farm entity, maintaining the same spirit. If, on the other hand, he thinks that the amount is too much for a potential successor, the farmer would like to hand over, but fears this may be impossible. He is therefore prepared to review his practices in order to cut down on the amount of work for the successor.

A farmer who regards his farm solely as capital or heritage does not have the same attitude to continuity. While the amount of work is accepted as normal, the way of working may have no particular significance, but the farmer may, however, want to pass on the heritage to one of his children. Alternatively, if the amount of work is thought excessive, the farmer will see it as a chore that he is obliged to suffer! He has no ambition as far as sustaining the spirit of the farm is concerned.

Neither the amount of work in itself nor archaic or modern methods of working prompt or thwart organizational sustainability. On the other hand, the fact that the farmer reasons according to an 'entity-cum-project' is crucial. The subjective opinions given on the method of working and on the amount of work are closely related to a desire for continuity, provided that the 'entity-cum-project' dimension is taken into account.

What implications for advice as regards work?

It is worth thinking about the chances of success in terms of improving the likelihood of continuity, arising from reorganizing the work on all these types of farms. Intuitively, extension advisors use different advisory practices depending on the type of farmer they are dealing with (the author was an agricultural advisor from 1980 to 1984). They predict that their efforts will sometimes be a 'waste of time' whereas 'the game will be worth the candle'

Table 5. Model of typology for advice on work reorganization.

	Amount of work	
Way of working	**Thought normal**	**Thought excessive**
Has a particular significance The farm is an entity-cum-project	The work can be reorganized provided that the significance of certain practices is treated carefully! Has no impact on organizational sustainability.	The work must be reorganized, the activities can be changed but not their spirit. This will greatly improve organisational sustainability.
Has no particular significance The farm is not an entity-cum-project	The work can be reorganised and the ways of working changed. Will contribute to continuity of power.	Work is a suffered chore. Potential reorganization will not improve continuity very much, except immediate continuity.

in other circumstances. We hope that they will find some theoretical suggestions here to support the practices dictated by their intuition.

The situations presented in Table 3 are worth considering for the person who has to give advice on reorganisation. The advisor's freedom of action and the results (improvements to continuity) he/she can hope for are not the same everywhere. Four variants, summed up in Table 5, are conceivable.

When a farmer thinks of the farm as an entity-cum-project and considers his amount of work to be 'normal', any advice on improving working conditions will be extremely limited. It is worth remembering that some practices are untouchable, including those that, at first sight, seem strange. They make sense to the farmer and give him the desire to carry on and to hand down. This is the case for Mr I, who refused his accountant's advice.

> To reduce Mr I's workload, his accountant advised him to introduce Charolais crossbreeds, and give up rearing Abondance heifers, without understanding that this cattle farm, although demanding, made sense for Mr I and was even a condition of his son, a trained inseminator and passionately fond of this breed, taking over: "*I see things in a certain way, that's how I am. Whenever my accountant comes, my management consultant, he says to me "you're losing masses of money with Abondance cattle". He wanted me to introduce Charolais but I didn't. I do pure breed, I want heifers (it means a bit more care and attention but ...) and I don't want cross-breeds, that's my opinion, that's how I see things, that's all.*"

Still in the context of the entity-cum-project, when the farmer thinks his amount of work excessive, he hopes and prays for a thorough reorganization that might drastically change his activities but not their 'spirit'. This is the case of Mr and Mrs J. The advisor then has to make sure that the new activities do not make the same time-consuming mistake.

> Mr and Mrs J. believe in organic farming but they have noticed that the practices are too hard to handle and too time-consuming. They therefore began to change them: by building a pen for the goats instead of herding them four hours a day, by reducing the acreage for growing vegetables and by accepting help from neighbors (and a round-baler) for hay. They are now thinking about other less demanding or less physical activities such as horse drawn carriage rides and guided tours of the farm.

When a farm is not regarded as an entity-cum-project and the amount of work is thought normal, it is possible to cut down on time spent or make changes to ways of doing things because they do not have any particular significance. Any improvement may contribute to one of the children taking over the farm. But the mere fact of reorganizing the work does not mean the farm will become an entity-cum-project. If the amount of work is thought excessive, it has to be reorganised so as to improve the lot of the current farmers. They will then be able to 'survive' for as long as possible. Nothing stands in the way of changing the activities or ways of doing things, but as they do not have a particular significance, it is unlikely that a reduction in working time will be able to erase the impression of suffering a chore. A really large-scale reorganization might, however, increase the chances of handing over to a family successor.

To conclude on the subject of advice, the advisor's task is more difficult when he or she works on an entity-cum-project. This is the case of most French farms that revolve around alternative farming systems. He or she has to distinguish what, among the working practices, makes sense for the farmer, what is a 'necessary sacrifice' on a scale with his work ethic. And these practices—however irrational they might seem—are untouchable if one wants to protect the entity-cum-project!

Conclusions

Cutting down on human labor on the farm is a credo of agriculture that puts strong emphasis on high productivity, a system of agriculture that works out its margins precisely in relation to working times and, by definition, wants to derive the greatest possible value per unit of labor hired to work on the farm. From the farmer's viewpoint, the work

required by an alternative system will seem to be greater in quantity and naturally different. This could be a major obstacle to the adoption of such systems and to their sustainability, but the issue is more subtle than that. Continuity at the point of succession depends to a great extent on the meaning that the farmer finds in his work, on the value he attaches to the spirit of his business. And alternative systems are particularly meaningful: the busy days, the use of plentiful labor and the often detailed or archaic practices are frequently the trademark of these alternative systems. As a result, advice on work reorganization cannot be managed with the same free hand or the same results among farmers who look at their situation in a different light.

Table 5 sheds light on the paradoxes presented at the start of this paper and, more generally, shows some implications for advice in matters of reorganizing farm work. But these recommendations should not be voiced without a reminder of their limitations. First, the scientific work that suggests these results was not initially devised to answer a question about work. This guarantees spontaneity and therefore reliability of the views collected, but does present some drawbacks. For instance, the sample included standard types of company, without being particularly concerned about dealing with all the possible types of companies. Secondly, the farmers interviewed were confined to Auvergne, so it would be helpful to test Table 5 on other regions and on other types of farms in terms of work organization. It would be interesting to link the farmers' subjective assessments of work to a calculation of their actual work time. Likewise, our survey has not yet been able to go on to verify the actual continuity of farms, which would need to be done in the future (in 20 years' time!).

A heavy workload is not always a handicap in an alternative system. On the contrary, it can be its hallmark, a way of expressing the farmer's ethics in his practices. That is why it is important to theorize about these observations, which French extension advisors in the field are aware of from experience.

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Does use of draft animal power increase economic efficiency of smallholder farms in Kenya?

P.M. Guthiga[1,*], J.T. Karugia[2], and R.A. Nyikal[2]

[1]Center for Development Research (ZEF), University of Bonn, Walter-Flex Str. 3, 53113 Bonn, Germany.
[2]Department of Agricultural Economics, University of Nairobi, PO Box 29053 Nairobi, Kenya.
*Corresponding author: pguthiga@uni-bonn.de

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Abstract

Draft animal power (DAP) has been identified as an environmentally friendly technology that is based on renewable energy and encompasses integration of livestock and crop production systems. Draft animal technology provides farmers with a possibility to cheaply access and use manure from the draft animals and farm power needed to apply renewable practices for land intensification. Compared to motorized mechanization, DAP is viewed as an appropriate and affordable technology especially for small-scale farmers in developing countries who cannot afford the expensive fuel-powered tractor mechanization. However, it is apparent that there is no consensus among researchers on how it affects crop yields, profit and production efficiency when applied in farm operations. This study addressed the question of whether using DAP increases economic efficiency of smallholder maize producers in central Kenya. Results of the study are derived from a sample of 80 farmers, 57% of whom used draft animals while 43% used hand hoes in carrying farm operations. In the study area, draft animals are almost exclusively used for land preparation and planting, with very few farmers applying them in the consecutive operations such as weeding. A profit function was estimated to test the hypothesis of equal economic efficiency between 'DAP' and 'hoe' farms. The results showed that farmers who used DAP obtained higher yields and operated at a higher economic efficiency compared to those who used hand hoes. The analysis underscores the viability of DAP in increasing profitability of small-scale farms; however, other aspects of the technology, such as affordability of the whole DAP package, availability of appropriate implements and skills of using the technology, must be taken into account when promoting adoption of DAP technology.

Key words: draft animal power, mechanization, smallholder farmers, profit function, economic efficiency

Introduction

Background information

Use of draft animals is an ancient practice that has persisted to the present times and its importance in developing countries as a source of power for carrying out farm operations is likely to continue in the foreseeable future. Draft animal power (hereafter referred to as DAP) has been identified as an environmentally friendly technology that is based on renewable energy and encompasses integration of livestock and crop production systems. Research work has linked the benefits of using DAP to several aspects such as: enhanced timeliness of carrying out farming operations, increased yield through improved seedbed preparation, deeper plowing, possibility of labor savings, reduced drudgery and possibility of income generation through off-farm transport and hiring[1].

Compared to the other parts of the world, sub-Saharan Africa (excluding Ethiopia) has had a shorter history of using draft animals[1]. In much of Africa, crop farming and cattle herding tended to be separate activities carried out by different tribal groups. In Kenya the use of oxen for cultivation was introduced in the 1920s by European settlers from South Africa[2]. The main draft animals used in Kenya include oxen, donkeys and, to a limited extent, camels. The use of draft animals for carrying out farm operations has been spreading rapidly in some areas and slowly in others in Africa[1]. The extent to which animal traction is used in Kenya is relatively low. It is estimated that only about 12% of smallholder farms (smallholder farms are here defined as farms whose total size is less than 10 ha) are using it, compared to 3% who were using tractors while over 80% were using hand tools[3]. This observation is

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also mirrored in other parts of Africa where DAP is adopted; for example in Uganda the contribution of animal power is estimated at approximately 8–9%[4] while in West African semi-arid tropics DAP is employed on less than 15% of total area sown[5]. Since its introduction in Kenya, little attention was given to introducing DAP to smallholder farmers[6]. On the contrary, the government tried to promote tractor mechanization which could have led to degrading of animal traction to a somewhat 'backward technology'. Further, the acquisition and maintenance of the animal traction package may require credit, veterinary and extension services and after sale services of the implements, which may not be readily available to the farmers. Other constraints to the use of animal traction that have been cited include lack of know-how by the farmers, limited availability of appropriate implements such as plow and weeders, potentially high cost of keeping and foddering draft animals and maintenance and repair of the implements.

In the first two decades after independence, the government promoted motorized mechanization through state-sponsored tractor hire schemes and tractor credit schemes. The thrust of these initiatives was to enable smallholder farmers to access tractors either through hire or purchase respectively. However, these efforts had limited success and proved unsustainable[1,7]. The government-managed tractor schemes were bureaucratic and were bogged down by tractor breakdowns that took too long repair. More importantly, in the small farms, use of tractors has proved not to be economically viable because most small-scale farmers cannot afford the initial cost of purchase, maintenance and operation (fuel) cost due to financial constraints. Furthermore, the farm sizes are small, scattered and have irregular shapes which make tractor operations difficult and in turn increase the operation costs. Subsistence nature of most small-scale farming is also unlikely to economically justify use of expensive tractors. Due to the limited success of the government-sponsored tractor hire services and tractor credit schemes, the use of animal traction for small farm mechanization has received somewhat more attention in the past two decades; for example, some government economic planning documents have highlighted the government's concern for the need for more research on the use of DAP[8]. However, there have not been significant practical efforts by the government to promote the adoption and widespread use of DAP, but stakeholders in the private sector have formed a national network for the promotion of animal draft technology known as KENDAT (Kenya Network for Draft Animal Technology).

Kenya's smallholder agriculture sector is very significant both in terms of volume and value of domestic production. According to the national development plan (2002–2008), the share of small-scale production was projected to average 54% of total agricultural production by the year 2008[9]. It is estimated that there are 3 million smallholder farms in Kenya with an average land size of 2 ha[10]. The dominance of the small farms is bound to continue as sub-division of larger farms continues due to prevailing land inheritance patterns. Therefore, given its relative importance, any strategy for stimulating agricultural growth in Kenya must inevitably target the smallholder sub-sector. Smallholder farmers generally use manual labor combined with low level technologies to carry out their agricultural production. In the past two decades a decline in agricultural productivity was shown among the smallholder farmers in Kenya[11]. Draft animal technology offers a viable potential to increase agricultural productivity using environmentally friendly and locally available resources.

Yield, profitability and efficiency effects of using DAP

The technical aspects of using animal draft technology are well documented but the user aspects of the technology have received less attention[12,13]. In Kenya, for example, several appropriate animal-drawn implements and accessories such as plows, cultivators, a variety of animal-drawn carts and harnesses have been developed and released to farmers but studies on profitability aspects of DAP are not commonplace. The overall low level of use of animal traction in sub-Saharan Africa has led to doubts being raised about its profitability and sustainable use. Actually there is no consensus among researchers on how the application of animal traction affects productivity or profitability[7]. This arises partly from the methodologies used in the studies, and partly due to the differences between the various study areas with regard to technical and socio-economic factors. The effects of mechanization on yields can be viewed as direct effects (higher yields, everything else being constant) and indirect effects, i.e., increased timeliness of carrying out farm operations, application of manure from draft animals. Direct effects of mechanization have not shown consistent results. The indirect effects of mechanization are less disputed, for instance timeliness of carrying out farm operations. Mechanization is seen as facilitating a more effective use of high yielding inputs.

Some research findings suggest that DAP is only profitable when socio-economic conditions permit a high level of utilization of animals and equipment[14,15]. Some studies have shown that use of DAP increased acreage without having significant impact on yields[16], while others indicate that DAP increased economic profitability of crop enterprises by smallholder farmers[7,17–19]. Therefore, there is need to carry out a case-by-case study to ascertain how use of DAP affects farm profitability. In many areas where DAP is used in Kenya, it is applied predominantly for primary tillage, with little or no application in subsequent operations. When it is applied for primary tillage, DAP has the potential of achieving expansion of cultivated area compared to the use of hand tools. Increased acreage implies that more labor would be needed in subsequent operations such as planting, weeding and harvesting. Although, in the context of small and declining farm sizes in Kenya the potential for significantly increasing acreage is limited, the

profitability of DAP in a setting of declining land sizes would still warrant investigation. As noted by Stevens[20], animal traction is rarely applied for weeding in Africa, even where plowing has been practiced for generations, mainly due to lack of affordable and readily available weeding implements and inadequate training of both the draft animals as well as the users. Weeding is recognized as a critical factor in determining crop yields; uncontrolled weed growth could reduce crop yields by up to 60%[21]. Weeding operation is cost intensive especially in terms of labor requirements. In many cases, farm labor available for weeding determines the final area that can be harvested. Given the potential of DAP in increasing farm profitability, this study attempts to shed light by comparing two groups of farmers: those using DAP and those using hoes for growing maize in central Kenya.

Materials and Methods

Study area

The study was conducted in Kirinyaga district, which is one of the six districts of the Central Province in Kenya. The district occupies an area of 1478 km^2 with 457,105 inhabitants distributed in four divisions within the district (Ndia, Gichugu, Mwea and Kerugoya Kutus). The district has a tropical type of climate with two rainfall seasons, i.e., the long rains (March to May) and the short rains (October to December). Usually planting of food crops is done during these two rainfall seasons because there is adequate rainfall that makes the district self-reliant in production of various types of food crops. The general landscape of the district rises from an elevation of 1480 m above sea level (ASL) in the south to over 6800 m ASL at the Mount Kenya peak. Farmers in the upper regions of the district put large portions of their farms under cash crops such as coffee and tea and also keep dairy animals for milk production. Farmers in the lower region do not produce tea or coffee due to unfavorable climate. Maize–bean intercrop is common in both the upper and lower regions. Maize is the main food crop in the larger part of the district and a household without maize grain is considered food insecure[22]. The district has a relatively high intensity of use of DAP especially for tillage operations. However, the use of DAP in Kirinyaga district closely follows a regional pattern. Most farmers who use DAP to carry out farm operations are concentrated in the lower parts of the district because it is relatively flat, hence more appropriate for using draft animals, and land sizes are also larger than in the upper areas. The traditional zebu oxen are predominantly used for tillage operations. A pair, or in some few cases two pairs, of oxen are used to pull a moldboard plow. DAP is predominantly applied in land preparation with limited application in weeding operations. There are, however, many farmers in Kirinyaga district who do not apply DAP to carry out agricultural operations, with many using hand tools and very few using tractors. Hiring out traction animals is a common practice in the study area, hence farmers who do not own oxen can access DAP through hiring.

Data sources

Farm level data for this study were collected using structured questionnaires covering the long rains period of 2001. Information gathered included household characteristics: acreage under maize, amounts of labor used in production, cost of hired labor, amounts of fertilizers used in maize production and their prices, family and hired labor input into maize production and inter-gender labor time allocation for farm work, home work and market work. A combination of multi-stage random and purposive sampling procedures was applied to obtain a sample of 80 farmers that were interviewed in this study. First, three divisions out of the four divisions were randomly selected, namely: Gichugu, Mwea and Ndia. In the next stage, two locations were randomly selected in each division. The selected locations were Baragwi and Karumandi in Gichugu division, Mutithi and Murinduko in Mwea division and Mutira and Inoi locations in Ndia division. At the location level, purposive sampling was applied to obtain a sample containing both 'traction' and 'hoe' groups. A total of 80 farmers were sampled for interview with 43% in the 'hoe' group and 57% in the 'DAP' group.

The concept of economic efficiency and its measurement

Efficiency is an elusive concept, defined and therefore measured differently by different disciplines. The economist, the engineer and the policy-maker, for example, all define efficiency differently. Policy implications arising from economic efficiency are important to both micro- and macro-level decision-making. Efficiency, as defined by Farrel[23] in his pioneering work on the subject, is the ability to produce a given level of output at the lowest cost. Two concepts of efficiency, technical and price or allocative efficiency, are clearly distinguished by Farrel[23]. A producer is said to be technically efficient if there is no possibility of producing the same amount of output with fewer inputs or producing more output with the same amount of inputs. Price efficiency (or allocative efficiency), on the other hand, refers to the proper choice of input combinations given the prevailing market prices. Economic efficiency combines both. It is possible for a firm to be either technically or allocatively efficient but be economically inefficient[24]. Technical and allocative efficiencies are necessary conditions, and when they occur together they are sufficient for achieving economic efficiency[25].

Many researchers have used the production function (a mathematical expression that attempts to capture the relationship between inputs combination and resulting output) as a tool to study economic efficiency. Some researchers have used the production function to separately estimate technical efficiency and allocative efficiency. The

production function approach assumes that all firms have identical ratios of inputs and outputs, hence only one point on the production plane would be observable. However, as noted by Ali and Flinn[26], a production function approach may not be appropriate when estimating the economic efficiency of individual firms because they face different prices and have different factor endowments. Due to these differences the firms will have different best practice production functions and, thus, different optimal operating points. Production function methods to test for allocative and economic efficiency have been criticized as suffering simultaneity bias because input levels are endogenously determined[26]. Problems of endogeneity can be avoided by estimating profit or cost function instead of production functions[27].

A firm's profit is a function of prices of inputs, price of output and the level of fixed inputs, which are all exogenous from the firms' point of view. A study by Yotopoulos and Lau[28] applied a profit function to compare efficiency of small and large farms in India. They further suggested that the same reasoning could be applied to compare different groupings such as owners versus share tenants or adopters of a new technology versus non-adopters. As noted by Khan and Maki[29] differences in economic efficiency among groups of farms (say users of a given technology and non-users) may result from variations in technical efficiency (larger output with equal amounts of inputs) and price efficiency (higher profits). Profit maximization is implied if the value of marginal product of each variable input is equal to its price. Thus we test the relative economic efficiency of the two groups of firms by comparing their actual profit functions.

Apart from differences in farm power sources, farms also differ in fundamental aspects of production such as differences in input application levels. This causes a difficulty in interpreting results. All other factors are not held constant. To overcome this problem two approaches could be applied: covariance analysis or before and after mechanization yields comparison. The latter method is inappropriate most of the time due to lack of data for comparison. Covariance analysis is a way of testing whether there are significant differences in the behavioral relationships between sets of observations. 'Covariance' analysis was carried out to isolate the direct effects of using animal traction, i.e. to test whether there are significant differences in the behavioral relationships between 'hoe' group and 'DAP' group. The results of the analysis showed that the two groups are statistically different from each other in the way the included independent variables explain variation in the profits from maize production.

The profit function model

In this study a restricted Cobb–Douglas Unit-Output-Price (UOP) profit frontier was applied in testing the relative economic efficiency of the effect of using DAP on economic efficiency of the sample farms in the study area because it was found to have the best fit of data despite there being other more flexible functions such as translog and quadratic functions. Profit functions (like their underlying production functions) can either be deterministic or stochastic in nature[30]. Stochastic functions, unlike deterministic functions, incorporate producer-specific random shocks besides the common shock that is allowed for all the producers in deterministic functions. The stochastic profit function is defined as:

$$\pi_i = f(P_{ij}, Z_{ik}, D_{ik}) \cdot \exp(\mu),$$

where π_i is normalized profit of the ith farm defined as the gross revenue less variable cost divided by farm-specific output price; P_{ij} is the price of the jth variable input faced by the ith farm divided by output price; Z_{ik} is the level of the kth fixed factor on the ith farm; D_{ik} is the dummy for farm mechanization ($D = 0$ if hoe was used and $D = 1$ if DAP was used); μ is an error term; and $i = 1, \ldots, n$, is the number of farms in the sample.

$$\mu = v_i - u_i,$$

where v_i's are assumed to be independently and identically distributed two-sided random errors, independent of the u_i's which are non-negative errors representing profit inefficiency.

The empirical model

The general form of the UOP profit frontier, dropping the ith subscript for the farm, is defined as:

$$\Pi = \beta_0 + \beta_1 \text{ANTRAC} + \beta_2 \text{WAGE} + \beta_3 \text{FERTZ} + \beta_4 \text{MACR} + \beta_5 \text{MSEED} + v - u,$$

where Π is normalized profit in Kenya Shillings (in the year 2001, one US dollar ($) was approximately equal to Ksh 75) defined as total revenue less total variable costs normalized by the price of maize. ANTRAC is a dummy variable with value 1 for 'traction' farms and 0 for 'hoe' farms. WAGE is wage rate in Ksh per person day normalized by the price of maize and FERTZ is the price of fertilizers in Ksh normalized by the price of maize. MACR is the acreage under maize in hectares and MSEED is the price of seeds in Ksh normalized by the price of maize. While v is the error term assumed to be independently and identically distributed two-sided random errors, independent of the u which is non-negative error representing profit inefficiency, β_i's are the regression coefficients.

Relative efficiency involves comparing efficiencies of two or more firms. As noted by Knox et al.[31], if two classes of firms have different degrees of technical and price efficiency and face similar prices in input and output markets, the firm class with higher profits is considered to be more economically efficient. The approach is that, given comparable endowments, identical technology, and normalized input prices, the UOP profit of two firms should be

Table 1. Descriptive statistics for the sample farmers.

Variable	'Hoe' group	'DAP' group
Land size (ha)***	1.06	2.81
Hired labor (person days)***	5.84	10.97
Acreage under maize (ha)***	0.96	2.40
Maize yield (kg/ha)***	883.03	1216
Value of fertilizer applied (in Ksh♯)***	2061.38	1103.02
Age of household head	50.38	51.33
Farming experience (years)	26.03	29.81

***Significant at 1% level.
♯Ksh = Kenya Shillings where 1 US $ = Ksh 75.

Table 2. Maximum likelihood estimates (MLE) of stochastic profit function regression.

Variable	Coefficient	Standard error	*t*-value
Constant***	804.86	108.57	7.41
ANTRAC (dummy)***	229.24	63.09	3.63
WAGE***	−1.28	0.29	−4.39
FERTZ***	−1.06	0.14	−7.75
MACR***	−10.16	24.28	3.17
MSEED	−0.09	0.08	−1.17
Log likelihood function	−487.51		
$\sigma_u^2+\sigma_v^2$	211.19	66.59	3.172***

***Significant at 1% level.
σ_u^2, σ_v^2, variance of the error term components u and v.

identical if they both maximized profits. If one firm is more price efficient, or more technically efficient, than the other, the UOP profits will differ even for the same normalized input prices and endowments of fixed inputs.

Results and Discussion

There was a significant difference on the land sizes, amount of hired labor, acreage under maize and value of fertilizers applied between 'DAP' and 'hoe' groups (Table 1). But there was no significant difference on age of the household head, years of formal schooling, years of farming experience and the family sizes between the two. Farmers who used DAP obtained significantly higher profits than those that used the hoe, as shown in Table 1.

The land sizes in the area of study are generally small regardless of whether one is in the 'DAP' or the 'hoe' group. Therefore, there is need to intensify land use through land augmenting technologies such as using fertilizers, high yielding crop varieties, nitrogen fixing legumes, cover crops, conservation tillage and such others. Use of draft animals could enhance land use intensification through cheap production and easy transporting of manure on the farm. Draft animals can also provide power for a wide range of labor intensive land management and erosion control systems, such as establishment of ridges along the contours in hilly areas. As noted by Noodwijk et al.[32] many renewable practices such as use of compost and green manures, use of cover crops, pruning of foliage from alley legumes and bushes are labor intensive, but DAP could help relieve scarce labor in the farms to perform these practices. The mean acreage under maize was 1.78 ha for the whole sample. This means that farmers in the study area on average put about 74% of their land holdings under maize, indicating the relative importance of maize crop in the study area. The average maize yield for the whole sample was 1074.20 kg ha^{-1}. There was a significant difference in the maize yield between the two groups of farmers. 'DAP' group on average obtained 1216 kg of maize ha^{-1} while the 'hoe' group obtained 883.08 kg of maize ha^{-1}. For the 'hoe' group yield varied between 441 and 1323 kg ha^{-1} while for 'DAP' group the maize yield varied between 2190.3 and 1852.2 kg ha^{-1}. The above results seem to concur with the proposition that DAP facilitates timeliness in land preparation and planting, as well as ensuring deeper plowing at the onset of rains which later translates to higher crop yields, all else being constant. The average value of fertilizers used in the sample farms was Ksh 811.92. The value ranged from Ksh 0.00 to Ksh 6250 with a median of Ksh 655. The 'hoe' group applied more fertilizers for maize production than the 'DAP' group on average. The mean value of fertilizers was Ksh 2061.38 and Ksh 1103.02 for the 'hoe' and the 'DAP' group respectively. 'DAP' group on average used less fertilizer than 'hoe' group but they still obtained higher yields on average. There is no straightforward explanation for this observation but there is a possibility that the yield increasing effect of using DAP overshadowed those of using fertilizers. Farmers in the 'DAP' group had a ready source of manure from the draft animals that they applied in their farms. Furthermore, crop rotation was more possible among 'DAP' farmers because some areas of the farm were set apart as non-cropped fallow for grazing the animals.

Regression analyses of the profit function are summarized in Table 2.

The signs of coefficients and their significance are consistent with the expectations of the profit function apart from the land size. As expected, the prices of variable inputs (wage rate, seeds and fertilizers) had a negative coefficient in the profit function. It is expected that the higher the price of variable inputs of production the less the profit that a farmer can attain. All the prices of variable inputs are significant in the model. This result to a large extent concurs with those of several others[24,26,28,29]. The coefficient of land is negative and significant, which implies that farmers with larger pieces of land were less efficient than those with smaller pieces of land. This observation could be attributed to the fact that farmers with smaller farm tend to intensify their production thereby making better use of inputs than those with larger farmers. The coefficient of mechanization was found to be positive and significant. This result indicates that use of animal traction

had a significant effect on increasing maize enterprise profits. Testing whether the coefficient of a dummy variable that differentiates the two groups of farms, is significantly different from zero we can test the hypothesis of relative economic efficiency. The results indicated that the coefficient of the dummy variable was significantly different from zero.

Conclusions

The present study examined profitability aspects of using animal traction as a strategy for small farm mechanization in Kirinyaga district in Kenya. The results indicated that use of animal traction (both owned and hired) all else being equal, increased both the yield and profits in maize production. This observation seems to concur with the proponents of use of DAP who say that if applied in farm operations animal traction can facilitate a more efficient use of other production inputs. DAP has a potential to enhance farmer's ability to adopt and use renewable practices such as use of animal manure, crop rotation, ridging and other renewable practices. Therefore, government and other stakeholders should promote use of animal traction as a way of increasing farm efficiency. For effective promotion of DAP as a source of farm power and its uptake by farmers various constraints that farmers face in adoption of animal traction, such as lack of capital and know-how, should be addressed. This is particularly important given the current status of low levels of adoption of a seemingly profitable technology.

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Organic banana production in Ecuador: Its implications on black Sigatoka development and plant–soil nutritional status

Maria Jimenez[1,*], Lieselot Van der Veken[2], Heleen Neirynck[2], Helga Rodríguez[1], Omar Ruiz[1], and Rony Swennen[2]

[1]Escuela Superior Politécnica del Litoral, Centro de Investigaciones Biotecnológicas del Ecuador, Guayaquil, Ecuador.
[2]Laboratory of Tropical Crop Improvement, Division of Crop Biotechnics, Catholic University of Leuven, Leuven, Belgium.
*Corresponding author: mjimenez@espol.edu.ec

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Abstract

Black Sigatoka, caused by the leaf fungus *Mycosphaerella fijiensis* Morelet, is a major constraint to banana production around the world. In Ecuador, the biggest banana-exporting country in the world, this disease has become increasingly aggressive. This has resulted in more fungicide applications, which have significantly increased costs in production and for the environment. Consequently, many banana growers have shifted to organic production, which produces greater economic returns as a result of higher sale prices. In addition, production costs are lower as no fungicides are applied. These organic bananas receive substantial amounts of organic products. This study describes the black Sigatoka disease and nutrient status in an organic banana plantation and compares it with a conventionally fertilized and fungicide-treated plantation. Black Sigatoka symptoms were evaluated in the vegetative and flowering stages under both production conditions and *in vitro* conditions. Univariate and multivariate descriptive statistics were used to analyze the parameters. Disease symptoms were more severe in leaves from the organic field than in leaves from the inorganic field, but the nutrient status (soil and foliar) did not differ between the two farms. Banana plants from the organic farm had 12 functional leaves at flowering and eight functional leaves at harvest. Average banana yields were over 40% lower for organic versus inorganic management; however, the average price received for organic bananas was over two times higher. Profit–cost analysis has shown that the organic banana farm was substantially more profitable than the inorganic one during the time period analyzed. These results indicated that bananas can be grown commercially without fungicides, and the lower productivity levels are compensated by higher prices of organic fruits in international markets. In addition, organic production has beneficial impacts on social and environmental issues.

Key words: banana, black Sigatoka, disease symptoms, liquid and solid bio-fertilizers, *Mycosphaerella fijiensis*, nutritional status, organic production

Introduction

In Ecuador 147,282 ha—nearly 0.6% of Ecuador's land area[1]—are used for banana cultivation. Commercial banana production takes place chiefly on the alluvial plains of the coastal lowlands in the provinces of Los Rios, Guayas and El Oro. About 10–12% of all economically active people in the country obtain some benefit from banana production. At presently, there are 5871 producers of banana and plantain. Unlike banana production in other exporting countries, production in Ecuador is not in the hands of multinational companies cultivating large areas. Instead, 80% of the total export production comes from growers maintaining areas smaller than 30 ha[1].

Black Sigatoka, caused by the ascomycete *Mycosphaerella fijiensis*, is a major economic constraint on banana production because it reduces the photosynthetic area and consequently reduces fruit filling and induces premature

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fruit ripening[2–5]. Yield losses range from 30 to 100% without fungicide applications[6,7].

In Ecuador the disease was reported in 1987 in Cavendish plantations near the northern coastal province of Esmeraldas[8]. From there, the disease spread rapidly throughout the country and affected all banana-growing areas. Since then, black leaf streak has been controlled with contact and systemic fungicides, and with mineral oil sprays. Disease forecast systems based on climatic data are rarely used. Also, the behavior of the fungus towards fungicides has not been evaluated by farmers so far[8]. Chemical control is based on alternating systemic fungicides (benzimidazole, triazole, morpholine and strobilurin) and contact fungicides (chlorothalonil and mancozeb). During the past 10 years, the number of fungicide cycles has increased dramatically in Ecuador. This is most probably due to a reduced sensitivity of *M. fijiensis* towards fungicides of the propiconazole group[9].

Because of environmental concerns regarding heavy pesticide use and soil degradation, many banana growers have shifted towards organic production. In such systems nutrients come from large amounts of organic matter, animal manure and rock phosphate. Key practices in this production system include the application of products of organic origin, soil management that stimulates biological activity, improved drainage, balanced nutrition, and removal of Sigatoka-infected leaves[10]. Today, over 5000 ha of bananas have been certified as organic in Ecuador, whereas many more are in the process of transition towards organic production.

Since black Sigatoka is such an aggressive airborne fungus, especially in large banana plantations consisting of Cavendish varieties only[11], it is puzzling to note that so many farmers in Ecuador adopt a fungicide-free production system. Thus the main aim of this study is to describe the specific agronomic practices of the organic production system while proving the presence and evaluating the aggressiveness of fungal isolates from organic (OR) and inorganic (IN) farms. Future aims focus on understanding why black Sigatoka is not devastating organic banana production.

Materials and Methods

Geographical situation and climatic characteristics

Two neighboring farms (7 km apart from each other) were selected: one farm receiving only inputs of organic origin and products approved for organic agriculture, and henceforth called the OR farm, and a farm receiving inorganic fertilizers and fungicides, hereafter called the IN farm. Both farms were located in the Guayas province (southern coast of Ecuador), near the village of Taura (2°18′00″S, 79°42′00″W). The close proximity was essential for conducting a comparative study on black Sigatoka because weather conditions (such as temperature, amount of rainfall and sunshine) influence fungal development[12].

Based on 10-year averages, weather data for this area were as follows: maximum temperature 30.6°C; minimum temperature 20.4°C; annual rainfall 842 mm; and relative humidity 80.6%[13]. The rainy season lasts from January until May, and the dry season from June until December.

General facts about the OR and IN farms

The OR farm covered 196 ha cultivated with the Cavendish cultivars[14] Williams (40%), Valery (40%), Grand Naine (10%) and Taura (10%), a local Cavendish selection. Plant density varied between 1450 and 1500 plants ha^{-1}. The plantation was at least 10 years old and was initially treated with synthetic fertilizers and pesticides. Eight years ago, these practices ceased. The OR farm no longer used pesticides against black Sigatoka. Presently black Sigatoka-infected leaves were pruned and nutrients were applied through solid bio-fertilizers and liquid bio-fertilizers (LBFs). Annual yields varied from 1100 to 1500 boxes ha^{-1} yr^{-1} depending on the geographical distribution of the different plots within the farm.

The IN farm consisted of 87.5 ha of the cultivar Williams. Plant density was 1450 plants ha^{-1}. This plantation was about 15 years old and annual yields were 2100 boxes ha^{-1} yr^{-1}. Black Sigatoka was controlled by both protectant (carbamates, chlorothalonil) and systemic (triazoles, benzimidazoles, morpholines and strobirulins) fungicides with seven or more fumigation cycles per year. Weeds were controlled with glyphosate every six to eight weeks in the rainy season and every 10 weeks in the dry season. The banana fertilization consisted of 400 kg ha^{-1} N mostly from urea, 600 kg ha^{-1} K, 80 kg ha^{-1} Mg, 2 kg ha^{-1} Zn and 1 kg ha^{-1} B spread over 13 application cycles within a year.

General facts relating to LBFs

Local micro-organisms (LM). The growth medium for micro-organisms consisted of boiled rice (150 g) and 400 ml of a mixture of sugarcane molasses (40 liters), fish meal (27 kg), NaCl (680 g) and water (80 liters). This mixture was boiled, put into small containers covered by a mosquito net and placed near trees bordering the banana field.

After 21 days, unidentified micro-organisms were harvested. Simultaneously another sugarcane molasses–fish meal–NaCl–water mixture was made and transferred to a 500 liter tank. Fifty to seventy pots with micro-organisms were transferred to the big tank immediately and were hermetically sealed. Micro-organisms were multiplied by transferring 50 liters of the raw material to another tank (500 liters), where 20 liters of sugarcane molasses were added to 430 liters of water. The tank was then hermetically sealed for 7 days, after which it was ready for use in the preparation of the LBF.

LBF preparation. The LBF was a fermented solution prepared from raw materials used in the OR farm. The

production of the LBF was based principally on fresh cow dung (40 kg), sugarcane molasses (4 liters), soybeans and bean leaves (10 kg), burned rice husks (10 kg) and LM (8 liters from the diluted LM tank). A 200 liter tank was filled with water, and the mixture was left to ferment under anaerobic conditions.

Once the fermentation process was finished, and prior to the foliar application, each tank of 200 liters was enriched with the following micronutrients: $MgSO_4$ (0.9–1.3 kg), H_3BO_3 (0.9–1.3 kg), $ZnSO_4$ (0.9–1.3 kg), $CuSO_4$ (0.9–1.3 kg) and $MnSO_4$ (0.9–1.3 kg). In the case of LBF for soil application, the enriching with K and P was done post-fermentation and with the following quantity per 200 liters tank: 3.2–6.4 kg of K_2SO_4 and 3.2–6.4 kg of phosphoric rock. After 60 days of anaerobic fermentation, the LBF was used as foliar or soil fertilizer. The LBF was sprayed on the leaves with a motorized backpack sprayer at a rate of 3 liters of pure bio-fertilizer diluted in 17 liters of water ha^{-1} $week^{-1}$. The soil LBF was applied weekly through the irrigation system at 100 liters ha^{-1}.

For approximately 1 year six samples were collected from the organic banana plantation to analyze the nutrient composition of the liquid products used as a main alternative in the management of black Sigatoka disease. Methodology for the chemical characterization is explained below.

Experiment one: black Sigatoka in vitro *development*

Thirty randomly selected plants in their vegetative and generative growth stage were twice selected from the OR and IN farms, during both rainy and dry seasons. The disease development was measured in fully extended leaves 1–6, leaf 1 being the youngest leaf emerged[15]. In the laboratory, an incubation medium was prepared with bacto agar Difco™ (4 g l^{-1}) added to distilled water and sterilized for 25 min at 121°C and 15 psi. Benzimidazole at 50 ppm was added to the Petri dish with a sterile syringe (Millex®-GP 0.22 µm) under sterile conditions. Leaf discs (5 cm^2) with the upper leaf surface on the medium were incubated under continuous light (4000 ± 200 Lux) at 26°C for 30 days approximately[3]. For each leaf disc, symptom development was recorded as: Stage 1: small whitish or yellow specks (less than 1 mm long); Stage 2: narrow reddish-brown or dark brown streaks, generally 2–5 mm long; Stage 3: streaks of 20–30 mm length; Stage 4: coalescing streaks broadened to a brown spot; Stage 5: elliptical black spot, usually surrounded by a yellow halo; Stage 6: center of the spot dry and clear grey, surrounded by a well-defined black border[16].

Experiment two: black Sigatoka disease development under greenhouse conditions

The experiment was repeated two times. Each time, 80 micropropagated Cavendish plantlets (Williams variety) were established in a greenhouse at 28°C and 96% relative humidity. Eight weeks after pot planting, plants were inoculated with *in vitro* conidia of *M. fijiensis* (3×10^4 conidia ml^{-1}) isolates from each farm. Three different media were used to produce *in vitro* conidia from monosporic colonies (both from the OR and IN farms). Potato dextrose agar (4%) Difco™ was used for colony growth for 7 days at 26°C and in complete darkness. Then, colonies were transferred to a mycophil medium for 20 days under the above-mentioned conditions. Conidiophores were induced by transferring small pieces of mycelium to V8 sporulation medium (pH 6). Conidia were produced after 7 days at 26°C and with continuous light (4000 ± 200 Lux).

The disease in the greenhouse was measured according to Alvarado et al.[17], which is a modification of the scale presented by Fullerton and Olsen[18], as follows: 0: leaf symptoms absent; 1: reddish flecks on lower leaf surface, no symptoms on the upper surface; 2: regular or irregular circular spots on the lower leaf surface, no symptoms on the upper surface; 3: regular or diffused light brown circular spots on the upper leaf surface; 4: black or brown circular spots, possibly with a yellow halo or chlorosis of adjacent tissues, on the upper leaf surface, areas of green tissue sometimes present; 5: black spots with dry center of gray color and the leaf completely necrotic.

Experiment three: black Sigatoka disease and nutritional status under field conditions

During 2003 and 2004, 80 banana plants of 2 m height were randomly chosen per season (rainy and dry) in the OR and IN farms. For each plant, leaves number 3 and 4 were evaluated weekly for 10 weeks for black Sigatoka symptom development[16]. The disease severity was evaluated on 20 plants per stage [vegetative (2 m height), flowering and harvest] with Gauhl's modification of Stover's severity scoring system[19]. This is based on the proportion of leaf area covered by disease symptoms: 0 = no symptoms; 1 = (stages 1, 2 or 3) but not more than 1%; 2 = less than 5% of the leaf affected; 3 = from 6 to 15% of the leaf affected; 4 = from 16 to 33% of the leaf affected; 5 = from 34 to 50% of the leaf affected; and 6 = more than 50% of the leaf affected.

At the experimental site the nutritional status was monitored during the years 2003 and 2004. Leaf samples[20] consisting of 15 cm wide strips were collected from the central part of leaf number 3 in 30 randomly chosen plants. The leaf nutrients content was compared with the leaf critical values (LCV)[21]. Fifteen soil samples were collected at 0–30 cm depth, twice a year, from each farm. This sampling depth was sufficient because the majority of banana roots develop in the topsoil[22]. Moreover, the soil nutrient content from both farms was analyzed using the chemical characterization data over time (5 years).

Elements such as K, Ca, Mg, Cu and Mn were determined by atomic absorption spectrophotometry. Other elements like B and S were determined by UV–VIS spectrophotometry and the analytical methods were based

Table 1. Banana yields and incomes during five continuous years (each year being the total of 52 weekly values) from OR and IN banana farms.

	OR farm						IN farm					
Parameters	**2001**	**2002**	**2003**	**2004**	**2005**	**Mean**	**2001**	**2002**	**2003**	**2004**	**2005**	**Mean**
Boxes ha^{-1} yr^{-1}	1507	1084	1379	1273	1118	1272	1773	2009	2181	2269	2543	2155
Tons ha^{-1} yr^{-1}	29	21	26	24	21	24	34	38	41	43	48	41
Mean annual price per box (US$)	6[1]	6.5[1]	7[1]	7.5[1]	7.5[1]	6.9	2.9[2]	3[2]	3.2[2]	3.25[1]	3.25[1]	3.1
Income ha^{-1} yr^{-1} (US$)	9039	7047	9653	9548	8386	8735	5141	6027	6978	7376	8264	6757
Profit ha^{-1} yr^{-1} (US$)	3789	1797	4403	4298	3136	3485	− 159	727	1678	2076	2964	1457
Production cost ha^{-1}, 5-year average	5250[1]						5300[1]					

[1] Personal comunication from farmers.
[2] Arias et al.[24].

on the *Official Methods of Analysis of AOAC International*[23]. Soil samples were processed by Mehlich extraction, whereas foliar samples were treated by wet-acid digestion. Nitrogen was analyzed by the Kjeldahl digestion procedure for plant tissue.

Statistical Analysis

The variables were classified into two types: discrete variables for the disease symptoms, and continuous variables such as nutrient content or yield per farm and the data of area under a curve of index disease evolution during evaluation time. Univariate descriptive statistics were applied for the estimation of central tendency parameters such as averages, and dispersion parameters such as standard deviation and coefficient of variance (CV). Multivariate descriptive statistics were used for analyzing similarities between the nutrient content over time in both farms. The soil nutrient content over time was analyzed by hierarchical cluster analysis using the Ward method and Euclidian distance.

Inferential statistics—analysis of variance (ANOVA) and the central limit theorem—were applied to compare the leaf nutrient content from experimental site versus LCV, by hypothesis contrast where H_0: $\mu = LCV$ versus H_1: $\mu > LCV$. The *t*-test was used for analyzing the yields, income and profit data, and by Levene's test the equality of variances was proved. All data were analyzed by running SPSS version 11 and MINITAB 13 for Windows.

Results and Discussion

Yields, incomes and profits at OR and IN farms

Over a 5-year period, banana yields for the IN farm averaged 40.9 t ha^{-1} yr^{-1} which was 69% greater ($P = 0.01$) than the 24.2 t ha^{-1} yr^{-1} for the organic farm (Table 1). However, prices over the 5-year period for the organic fruit averaged over two times that of conventional fruit (6.9 versus 3.1 dollars per box) resulting in gross product sales the same or higher on the OR farm (8735 versus 6757 dollars ha^{-1} yr^{-1}; $P = 0.025$). Hence on an annual basis the IN farm was more productive than the OR farm (Table 1). However, as organic fruit fetches much higher prices, the lower yield in the OR farm was more than compensated. Therefore, an average 16% higher net profit (3485 versus 1457 dollars ha^{-1} yr^{-1}; $P = 0.023$) was calculated in the OR farm compared to the IN farm during 2001–2005.

Nutrient composition of LBF

The nutrient composition of the LBF was monitored over a period of 10 months (Table 2). The high CV (from 77.4 to 241.5%) indicated that the mineral composition of the LBF varied substantially during the year. This was not surprising since the LBF was made from locally available materials that also varied during the year[25,26]. Moreover, the quantities of the different materials used for the

Table 2. Nutrient composition of LBF samples prepared and applied on six different dates by foliar application in the OR farm.

Elements	Samples						Mean	CV (%)
	Mar-03	Jun-03	Sep-03	Oct-03	Nov-03	Jan-04		
	Macronutrients (mg 100 g^{-1} dry material)							
P	1339.0	10.7	10.7	87.5	808.3	3693.2	991.6	144.0
K	3955.0	601.5	68.6	5808.8	7258.3	4252.8	3657.5	77.6
Ca	2634.0	49.4	34.3	3004.8	3165.8	2297.7	1864.3	77.4
Mg	912.0	35.9	19.8	1550.7	1685.0	1022.4	871.0	82.3
Na	2623.0	89.5	46.2	4944.9	6873.3	3754.3	3055.2	88.6
	Macronutrients (mg l^{-1} fresh)							
N (total)	5927.0	1030.2	412.9	637.0	261.0	1023.0	1548.5	140.0
	Micronutrients (mg 100 g^{-1} dry material)							
Si	93.5	0.9	0.5	494.1	607.5	180.2	229.5	113.4
Cu	1.5	0.0	0.0	1.5	1.2	0.6	0.8	85.0
Fe	293.3	2.5	2.6	253.7	226.7	239.3	169.7	77.4
Zn	8.0	0.1	0.2	11.0	17.8	2.9	6.7	104.5
B	0.6	0.1	0.1	4.7	10.4	3.7	3.3	123.3
Mn	38.2	1.6	11.9	15.3	6134.2	5.9	1034.5	241.5

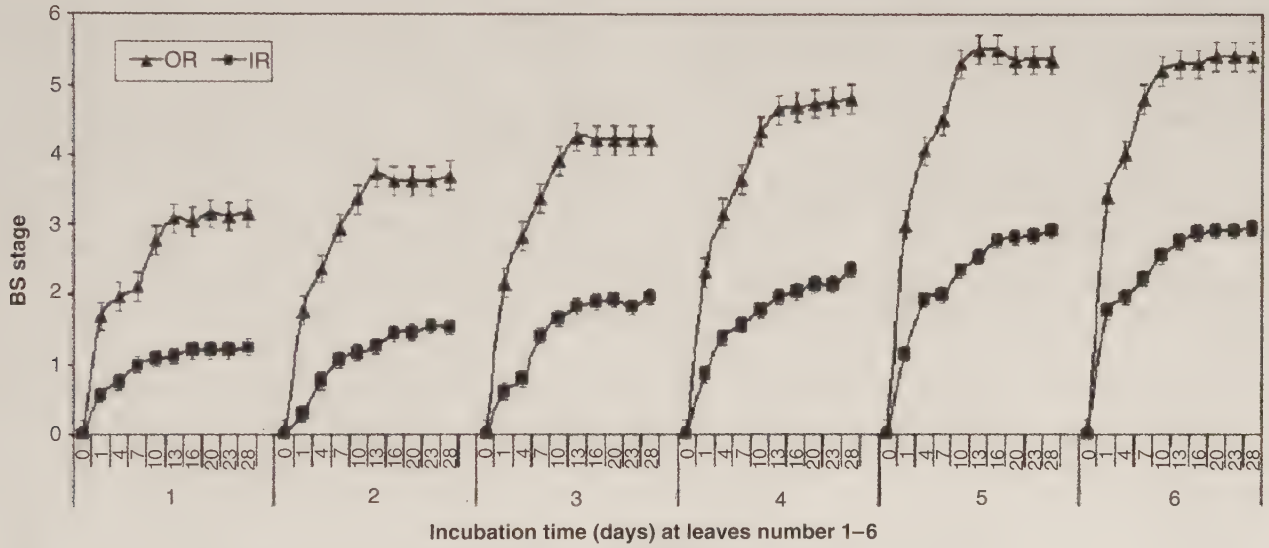

Figure 1. Black Sigatoka (BS) symptoms evolution during 28 days on *in vitro* cultured leaf discs of flowering plants. Leaves 1–6 were infected during the rainy season in an OR and IN farm.

fermentation process were not well controlled. Table 2 shows that macronutrients like K, Na and Ca and micronutrients such as Fe, Si and Mn were present in the largest quantities.

Black Sigatoka development under in vitro *conditions*

Leaf discs of banana leaves 1–6 were collected from vegetative growing and flowering plants in the organic and inorganic fields. Black Sigatoka symptoms under *in vitro* conditions were more pronounced in leaf discs from the OR farm than in leaf discs from the IN farm, both in plants in the vegetative growing stage (data not shown) and in the flowering stage (Fig. 1). The pattern of black Sigatoka symptom evolution was similar for all leaves, in both farms and at both plant stages. However, differences in symptom evolution in the OR and IN farms were more pronounced in the flowering plants and with increasing leaf age.

While in the generative plant growth stage black Sigatoka in leaves 5 and 6 reached about stage 5 in the OR farm after 28 days incubation, it reached only stage 3 in the IN farm (Fig. 1). In the vegetative growth stage, black Sigatoka was also more pronounced in the OR farm than in the IN farm but differences were smaller (scores 2 and 1 for leaf 5 after 28 days' incubation for the OR and IN farms respectively (data not shown). The symptom evolution in the vegetative growth stage did not show any differences, but were significantly different in the

Table 3. Black Sigatoka symptoms accumulation (area under the curve) in six leaves from banana plants in their generative stage in an OR and IN farm ($n = 50$ per leaf and per farm).

Leaf number	OR Mean ± SE	IN Mean ± SE	*t*-Test (*P* value)
1	20.3 ± 1.7	9.0 ± 0.7	0.000*
2	24.2 ± 2.3	10.5 ± 0.9	0.000*
3	29.6 ± 3.1	14.7 ± 1.4	0.000*
4	35.2 ± 2.8	15.6 ± 1.2	0.000*
5	38.3 ± 3.5	21.4 ± 1.4	0.000*
6	39.7 ± 5.0	20.8 ± 2.0	0.000*

* Significant differences at $\alpha = 0.05$.

generative growth stage between the OR and IN farms (Table 3).

These results corresponded to symptom development under field conditions[12,27]. The lower infection level in the IN farm was attributed to fungicide residues. The increase in black Sigatoka development stages was linked to leaf age and plant stage. This might be caused by the lower nutrient status of the leaves[28–31] when aging leaves export nutrients to younger leaves and the developing bunch. The translocation of nutrients from the older to the younger plant tissue could also contribute to higher disease development[26].

Black Sigatoka disease development under greenhouse conditions

In order to eliminate environmental effects and the possible effects of different *M. fijiensis* isolates, disease symptoms were monitored on micropropagated plants grown under greenhouse conditions. Disease symptoms were similar to those observed in the field on mature plants for conidia originating from both farms[12]. The disease development generated by both isolates was similar regardless of the origin of the conidial suspension during each evaluation time (Fig. 2). In addition, *in vitro* characterization of both isolates showed similarities in the organ's development (data not shown).

Black Sigatoka disease and nutritional status under field conditions

In both growing seasons, black Sigatoka disease symptoms were more pronounced in the OR farm than in the IN farm (Fig. 3), and the accumulation of the disease symptoms in leaves 3 and 4 confirmed significant differences between OR and IN farms in relation to the season (data not shown). This was attributed to the fact that black Sigatoka was kept under control in the IN farm by frequent fungicide applications. In the OR farm however, the fungus was not controlled by fungicides, but leaves received LBF on a regular basis. This conclusion is supported by other authors[16,32].

Disease severity was always lowest in the IN farm during any plant growth stage, indicating good chemical control (Table 4). This resulted in a significantly higher number of standing leaves in the IN farm at any growing stage except flowering. Despite the better Sigatoka control in the IN farm, the Sigatoka seemed to have been adequately controlled in the OR farm. Indeed, at harvesting 8.5 functional leaves were observed, while 6–7 functional leaves are

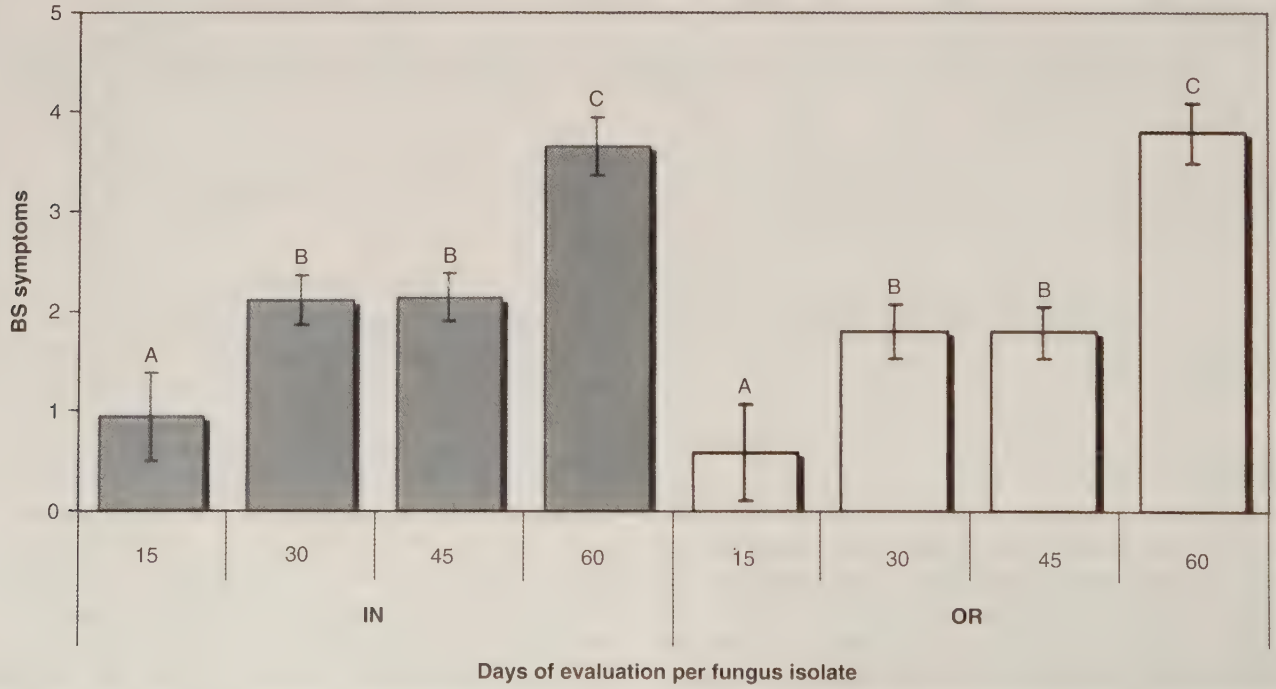

Figure 2. Black Sigatoka (BS) symptoms evaluation over 60 days on micropropagated banana plants grown in the greenhouse and inoculated with a *M. fijiensis* conidial suspension from an OR and IN farm.

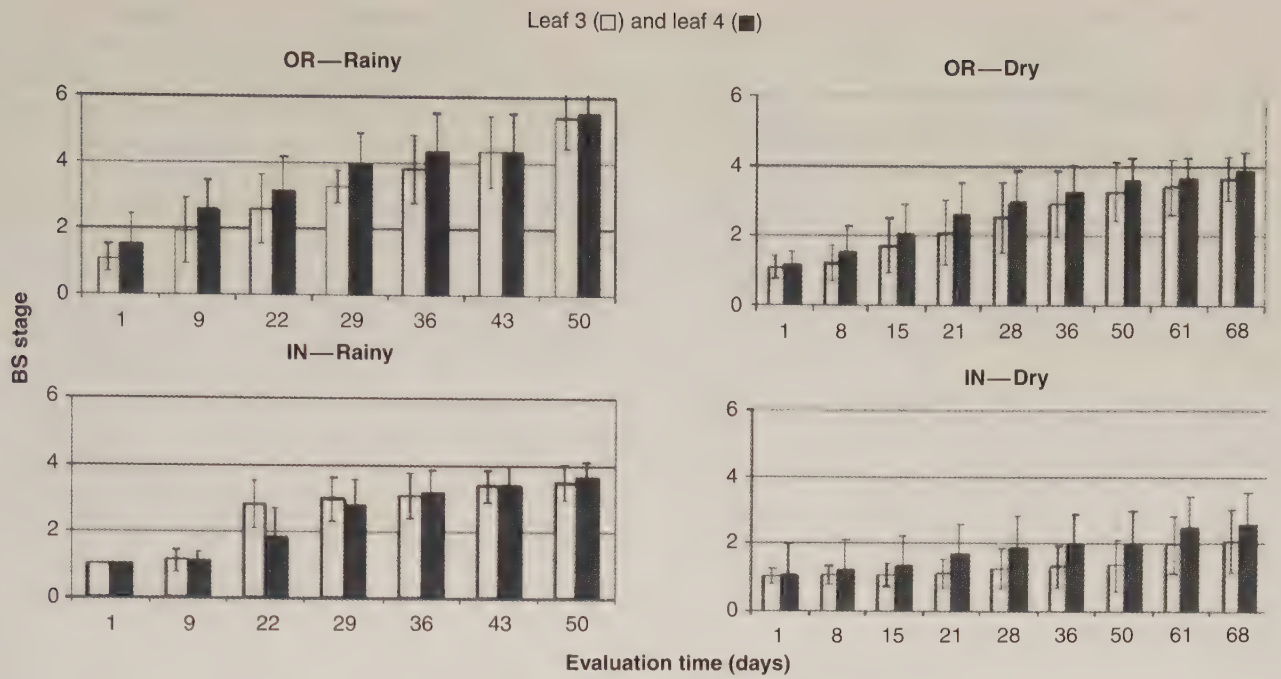

Figure 3. Black Sigatoka (BS) symptoms evolution in leaf 3 and leaf 4 in an OR and IN farm during the rainy and dry seasons.

Table 4. Standing leaves and black Sigatoka severity (%) in banana plants at different growth stages in an OR and IN farm ($n = 50$ plants per growth stage).

	Plant growth stage		
	Vegetative	Flowering	Harvest
Parameters		Mean ± SE	
		OR	
Number of standing leaves per plant	11.9 ± 0.136	12.5 ± 1.193	8.5 ± 0.157
Leaf area with black Sigatoka symptoms (%)	2.9 ± 0.271	3.3 ± 0.333	6.3 ± 0.437
		IN	
Number of standing leaves per plant	13.03 ± 0.136	13.4 ± 0.171	9.7 ± 0.165
Leaf area with black Sigatoka symptoms (%)	0 ± 0.017	0 ± 0.015	1.2 ± 0.153
		ANOVA (*P* value)	
Number of standing leaves per plant (OR versus IN)	0.000*	0.000*	0.559 ns
Leaf area with black Sigatoka symptoms (%) (OR versus IN)	0.000*	0.000*	0.000*

* Significant differences at $\alpha = 0.05$.
ns = not significant at $\alpha = 0.05$.

considered adequate[33]. Hence, black Sigatoka in the OR farm was properly controlled, avoiding serious yield losses.

For bananas little is known about optimal nutrient requirements in relation to disease resistance. Unpublished data from Mendez et al., mentioned by Romero[34], reveal that N and K imbalances favor black Sigatoka development. Results in Uganda show that the intensity of black Sigatoka disease has a highly significant relationship with factors such as organic matter content in the topsoil and amounts of Ca and Mg[10] in the soil. Deficiencies in Ca and P content predispose the plant to fungal and bacterial infection[35]. Black Sigatoka severity can be reduced if soil fertility and organic matter are high, such as in backyards that collect household refuse[36].

Since both farms received nutrients in different ways, the soil nutrient status was evaluated. Both the OR and IN farms had the same nutrient content (Table 5) except for Zn, which was significantly higher in the IN farm. On the other hand, higher electrical conductivity (EC) values in soil from the IN farm may result from the continuous use of synthetic fertilizers and subsequent nitrification of urea.

Also, macro- and micronutrient content in leaf 3 of banana plants from OR and IN farms was similar, and all nutrient requirements were those recommended for banana

Table 5. Soil parameters and nutrients from OR and IN farms.

	OR	IN	*t*-test
	Mean ± SE		(*P* value)
pH	6.7 ± 0.1	6.4 ± 0.1	0.12
OM (%)	1.9 ± 0.2	1.6 ± 0.2	0.44
EC (dS m^{-1})	0.7 ± 0.2	0.8 ± 0.2	0.75
CEC (meq 100 ml^{-1})	21.4 ± 1.2	22.9 ± 1.5	0.52
Macronutrients			
(mg kg^{-1})			
NH_4	6.0 ± 2.0	5.5 ± 2.5	0.89
P	15.50 ± 2.50	12.5 ± 0.5	0.44
(meq 100 ml^{-1})			
K	0.4 ± 0.1	0.6 ± 0.1	0.24
Ca	14.1 ± 0.7	13.8 ± 1.3	0.86
Mg	6.7 ± 0.3	8.2 ± 0.0	0.12
Na	0.1 ± 0.0	0.1 ± 0.0	0.35
Micronutrients			
(mg kg^{-1})			
Cu	8.4 ± 0.7	9.2 ± 1.10	0.61
Fe	52.9 ± 12.8	52.9 ± 14.0	1.00
Zn	4.6 ± 0.3	7.5 ± 0.3	0.019*
B	0.6 ± 0.2	0.7 ± 0.3	0.86
Mn	3.9 ± 0.7	4.5 ± 1.7	0.79
S	46.0 ± 15.3	21.4 ± 2.2	0.35

* Significant difference at $\alpha = 0.05$.
OM, organic matter; EC, electrical conductivity; CEC, cation exchange capacity.

production[37,38]. Moreover, the leaf nutrient content from OR and IN farms was separately compared with the banana LCV. In the OR farm the concentrations of K (StDev = 0.12) and Fe (StDev = 7) were significantly higher ($P = 0.05$), as was B (StDev = 1.05) in the inorganic farm (Table 6). Yet soil nutrient data over a 5-year period clearly show that soils in both farms can be separately grouped (data not shown).

Conclusions

Cavendish plantations are reported to depend on synthetic fungicides to remain productive where black Sigatoka disease occurs. However, present results indicate that bananas can be grown commercially without fungicides in Ecuador. Indeed in an OR farm under study an average productivity of 23 t ha^{-1} yr^{-1} was recorded, with an average of 8.5 functional leaves, and 6.3% disease severity at harvest.

This OR farm received organic products made on-farm by fermentation of waste products, which vary tremendously from application to application. However, with inorganic fertilizers and fungicides, yield and black Sigatoka control is higher (42 t ha^{-1} yr^{-1} with 9.7 functional leaves and a disease severity of 1.3% at harvest). Comparative results both *in vitro* and in the greenhouse showed that the black Sigatoka fungus of both farms interacts in the same way with plants from the OR and IN farms. Soil analysis shows no differences between the OR and IN farms except

Table 6. Nutrient concentration on a dry matter basis in leaf 3 of banana plants from OR and IN farms and comparison with the LCV.

	OR		IN		
	Mean ± SE	OR mean versus LCV (*P* value)	Mean ± SE	IN mean versus LCV (*P* value)	Contrast means (OR versus IN) (*P* values)
Macronutrients					
(%)					
N	2.5 ± 0.2	0.63	2.5 ± 0.2	0.58	0.93 ns
P	0.3 ± 0.1	0.19	0.2 ± 0.0	constant values	0.46 ns
K	4.5 ± 0.1	0.03*	4.9 ± 0.4	0.10	0.46 ns
Ca	0.7 ± 0.1	0.92	0.7 ± 0.1	0.84	0.78 ns
Mg	0.4 ± 0.0	0.18	0.4 ± 0.0	0.05	0.45 ns
S	0.2 ± 0.1	0.36	0.2 ± 0.0	0.75	0.45 ns
Micronutrients					
(ppm)					
Cu	10.1 ± 1.1	0.19	14.2 ± 4.4	0.21	0.51 ns
Fe	123.2 ± 5.0	0.03*	145.2 ± 56.7	0.21	0.76 ns
Zn	20.7 ± 3.8	0.83	16.5 ± 2.8	0.92	0.47 ns
B	28.8 ± 5.0	0.18	25.9 ± 0.8	0.05*	0.66 ns
Mn	141.8 ± 25.7	0.95	106.5 ± 7.6	0.99	0.39 ns

* Significant difference at $\alpha = 0.05$.
ns = not significant at $\alpha = 0.05$.

for Zn, yet cluster analysis over a 5-year period allowed a clear separation between the OR and IN farms.

Leaf nutrient analysis shows that all plants had optimal nutrient amounts except for K and Fe in the OR farm, and B in the IN farm. The fact that organic fruit costs twice as much as inorganic fruit means greater profits and makes organic banana production a profitable agricultural system. Therefore further research is needed to investigate whether the Sigatoka disease in the OR farm is controlled due to a fungicidal action of the bio-fertilizer and/or whether some nutrients or nutritional balance have an effect on the plant defense system.

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Evaluation of different pig slurry composts as fertilizer of horticultural crops: Effects on selected chemical and microbial properties

Margarita Ros*, Carlos García and Maria Teresa Hernandez

Department of Soil and Water Conservation and Organic Waste Management, Centro de Edafología y Biología Aplicada del Segura (CEBAS-CSIC), PO Box 164, 30100 Espinardo, Murcia, Spain.
*Corresponding author: margaros@cebas.csic.es

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Abstract

The excessive use of mineral fertilizers affects soil quality, gives rise to environmental problems and consumes energy. In contrast, organic amendment may improve soil quality at the same time as providing nutrients to plant. The aim of the work was to study the effects on crop yield and soil microbial activity of the successive addition of mineral fertilizers and fresh pig slurry before each successive crop compared with one sole application of different pig slurry composts (solid fraction of a pig slurry (CSFPS) and fresh pig slurry plus wood shavings (1 : 1 v/v; CPS + WS) before planting the first crop. Compost-treated soils exhibited higher organic carbon content than inorganically fertilized soils, throughout the experimental period. However, N content in the former soils was lower than in the latter after the second crop. Nevertheless, yields obtained with repeated additions of fresh pig slurry or with a sole application of pig slurry composts were similar to those obtained with repeated mineral fertilization. After the horticultural crops, organically treated soils generally showed higher values of both microbial biomass and metabolic microbial activity (measured as basal respiration and dehydrogenase activity) than the soil receiving mineral fertilization. Subsequently, the organically amended soils showed higher protease, phosphatase and β-glucosidase activities than the inorganically fertilized soil and similar levels of urease activity. From this study it can be concluded that both fresh and composted pig slurry can be used as an alternative for mineral fertilizer in growing horticultural crops and maintaining soil quality.

Key words: fresh pig slurry, compost, mineral fertilizers, crop yield, enzyme activities, soil quality

Introduction

Animal manure is the major source of organic matter used in agriculture, although wastes from food processing and other industrial processes, together with municipal wastes, are also often used[1,2]. The uncontrolled application of fresh pig slurry to soil can generate environmental problems, including an excess of nitrates and salts and/or the accumulation of phosphorus and metals in soils; the potential transport of pathogens via air or water; and air emissions of ammonia, methane, hydrogen sulfide, nitrous oxide and odorants[3,4]. In past decades, increasing environmental regulation concerning farming has resulted in great attention being paid to animal manures for land application[5,6]. Separation of pig slurry solid fraction and composting are two possible pre-treatment alternatives to obtaining a safer organic matter from animal manures in particular and organic wastes in general.

Although, sometimes the composting process may turn out to be expensive, the final compost is a mature organic matter without pathogens and/or toxic compounds[7,8], that can be recycled in the soil as a source of organic matter and plant nutrients, improving soil quality and crop production and substantially contributing to the sustainability of soil functions[9], replacing as much inorganic fertilizer as possible to avoid environmental problems and energy consumption[7].

Microorganisms, especially bacteria and fungi, and soil enzymes, mostly of microbial origin, are responsible for the biological transformations that make nutrients available to plants and they are involved in many processes essential for

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the long-term sustainability of agricultural systems[10]. Thus, the effects of particular organic amendments on soil microbial activity under a given cultivation system and climatic conditions need to be assessed. Biochemical properties such as microbial biomass carbon, basal respiration and hydrolase activities (urease, phosphatase and β-glucosidase) have been used widely to evaluate the impact of different organic and inorganic fertilizers on the entire soil and plant resource[9,11].

The objective of this experiment was to study the effects on yield and microbiological soil properties of multi-applications of mineral fertilizer compared with a single application of different pig slurry composts or multi-applications of fresh pig slurry, to a semi-arid soil under horticultural plant cultivation, as well as to evaluate the possibility of reducing or substituting mineral fertilizers with fresh or composted pig slurry without reducing crop yield.

Materials and Methods

Experimental design

Two successive horticultural crops, broccoli (November 2002–January 2003) followed by lettuce (March–May 2003), were grown in experimental plots located in Lorca (SE, Spain), very close to a pig farm. The soil had a pH (H_2O) of 7.7 and electrical conductivity (EC) of 1.35 dS m^{-1}. The soil contained 18 g kg^{-1} total organic carbon, 0.3 g kg^{-1} Kjeldahl N, 1.8 g kg^{-1} total P and 8.9 g kg^{-1} total K. The soil had been cultivated conventionally with lettuce until 1992. Since then, it had been abandoned, and no vegetation had grown in it during this time.

Randomized plots (4 m × 6 m) were set up with the following treatments:

(i) Mineral fertilizer (MF) applied one week before planting each crop and according to the crop requirements (broccoli 182 kg N (NH_4NO_3) ha^{-1}, 155 kg P_2O_5 ha^{-1}, 112 kg K_2O ha^{-1}; lettuce 170 kg N (NH_4NO_3) ha^{-1}, 100 kg P_2O_5 ha^{-1}, 170 kg K_2O ha^{-1}).
(ii) Fresh pig slurry (PS) applied one week before each crop at a rate of 100 t ha^{-1} by spreading from a tank and incorporation by ploughing into the top 0–20 cm of the soil.
(iii) Compost from the solid fraction of pig slurry at equivalent of 15 t ha^{-1} (dry weight) (CSFPS).
(iv) Compost from a mixture of pig slurry and wood shavings (1 : 1, v/v) at equivalent of 15 t ha^{-1} (dry weight) (CPS + WS).

Treatments were set up in triplicate. Composts were applied only once, one week before the first crop and were incorporated by ploughing into the top 0–20 cm of the soil. The quantities of fresh pig slurry and composts added to the soil were calculated to give a total N amount similar to that provided by the successive additions of mineral fertilizer (Table 1).

Table 1. Total amount of C, N, P and K added to the soil with each treatment in the experiment period.

Treatment[1]	Organic C (kg ha^{-1})	Total N (kg ha^{-1})	Total P_2O_5 (kg ha^{-1})	Total K_2O (kg ha^{-1})
MF	0	352	255	282
PS	1058	358	392	369
CSFPS	3630	330	545	228
CPS + WS	5955	300	572	132

[1] MF: mineral fertilizer; PS: fresh pig slurry; CSFPS: compost from the solid fraction of pig slurry; CPS + WS: compost from a mixture of pig slurry and wood shavings.

The solid fraction from pig slurry was obtained using a 'compactor' type solid–liquid phase delimiter, with a cylindrical sieve and a never-ending screw (GEA Westfalia-Separator, Germany). Composting was carried out in outdoor piles with periodical turning over a period of 3 months[8]. The main characteristics of the organic amendments are shown in Table 2. Pathogen content was below the limits established in the literature[12] and the heavy metal content was below the limits established by Spanish legislation (Real Decreto 1310/1990).

Soils were sampled, in October 2002, before planting the broccoli crop (after adding the different organic amendments and mineral fertilizer to the soil), on March 2003, after broccoli harvest, and on May 2003, after lettuce harvest. Ten soil cores (0–20 cm) from each treated plot were randomly collected and bulked. The samples were immediately transported to the laboratory, sieved (< 2 mm) and stored at 4°C for analysis.

Chemical analysis

EC and pH were measured in an (1 : 5) aqueous extract. Total organic carbon (C_{org}) was determined by oxidation with potassium dichromate in an acid medium and measurement of the remaining dichromate with Mohr's salt[13]. Nitrogen (N) was determined by the Kjeldahl method modified by Bremner and Mulvaney[14]. The nitrate content was determined by high performance liquid chromatography (HPLC) after extraction for 2 h with hot water (40°C) (1 : 10, w/v). Ammonium was determined by ammonium selective electrode after extraction with 2 M KCl[15]. Total P, K and heavy metals were determined by atomic absorption spectroscopy after wet acid digestion of the samples.

Microbial activity and microbial biomass carbon

Soil respiration was measured as the CO_2 evolved during an incubation period of 40 days from 30 g of soil moistened at 60% of its field capacity and placed in hermetically sealed flasks kept in the dark at 28°C. The CO_2 emitted was

Table 2. Characteristics of organic amendments (dry weight).

	Fresh pig slurry[1]	Compost from the solid fraction of pig slurry	Compost from a mixture of pig slurry and wood shavings
pH (H_2O)	7.5	6.7	6.9
EC ($dS\,m^{-1}$)	13.2	5.6	2.8
Total organic C ($g\,kg^{-1}$)	5.3	242	397
Kjeldahl N ($g\,kg^{-1}$)	1.8	22	20
NH_4^+ ($g\,kg^{-1}$)	1.6	0.37	0.18
NO_3^- ($g\,kg^{-1}$)	0.008	12.9	0.6
P_t ($g\,kg^{-1}$)	2.0	36.35	38.10
K_t ($g\,kg^{-1}$)	1.85	15.20	8.80
Na ($g\,kg^{-1}$)	0.32	3.90	2.43
Ca ($g\,kg^{-1}$)	0.12	117.7	11.4
Mg ($g\,kg^{-1}$)	0.009	11.30	2.70
Cu ($mg\,kg^{-1}$)	16.9	482	128
Zn ($mg\,kg^{-1}$)	31.3	1655	319
Cr ($mg\,kg^{-1}$)	0.31	< 0.1	< 0.1
Pb ($mg\,kg^{-1}$)	0.32	< 0.1	< 0.1
Cd ($mg\,kg^{-1}$)	< 0.05	< 0.1	< 0.1
Ni ($mg\,kg^{-1}$)	0.32	< 5	< 5
Escherichia coli ($cfu\,g^{-1}$)	2.4×10^3	3	9
Salmonella in 25 g	Absence	Absence	Absence
Streptococcus faecalis ($cfu\,g^{-1}$)	4.6×10^3	24	43
Germination index (%)	140	160	217

[1] Average of each application.

measured by infrared (IR) spectrophotometer daily during the first week and once each week thereafter. Basal respiration was calculated by dividing the CO_2 evolved during the incubation period by the duration of the incubation experiment. Microbial biomass carbon (C_{mic}) was determined by fumigation with ethanol-free $CHCl_3$ and extraction with K_2SO_4[16].

Soil enzyme activities

Dehydrogenase activity was determined by Skujins' method modified by Garcia et al.[17]. Sample (0.5 g) at 60% of field water holding capacity was treated with 0.2 ml of 0.4% 2-*p*-iodophenyl-3-*p*-nitrophenyl-5-phenyltetrazolium chloride (INT) in distilled water for 20 h at 22°C in darkness. The iodo-nitrotetrazolium formazan (INTF) formed was extracted with 10 ml of a mixture of 1 : 1.5 ethylene/chloride acetone and measured spectrophotometrically at 490 nm.

Urease was determined by incubation of 0.48% urea with borate buffer at pH 10 (2 h at 37°C). Activity was determined by measuring the released NH_4^+ with a spectrophotometer (HeλIos α, Thermo) at 690 nm[18]. Protease activities were determined by incubation of 0.03 M *N*-α-benzoyl-L-argininamide (BAA) with 0.1 M phosphate buffer at pH 7 (1 h at 40°C)[19]. Activity was determined by quantification of the released NH_4^+ with a spectrophotometer (HeλIos α, Thermo) at 690 nm[18]. Phosphatase and β-glucosidase activity were determined using 0.115 M *p*-nitrophenyl phosphate (PNPP) dissolved in 0.1 M maleate buffer (pH 6.5) (1 h at 37°C)[20] and 0.05 M *p*-nitrophenyl-β-D-glucopyranoside (PNG) dissolved in modified universal buffer (MUB-HCl buffer pH 6)[21], respectively, as substrates. These assays are based on the release of *p*-nitrophenol (PNP) which was measured with a spectrophotometer (HeλIos α, Thermo) at 400 nm.

Statistical analysis

Statistical analysis was performed using SPSS 13.0. The statistical model was a completely randomized design with four treatments and three replicates per treatment, sampled at three times. Two-way ANOVA for treatments and sampling time, and one-way ANOVA for treatments at each sampling time were used followed by Tukey's[22] significant difference ($P \leqslant 0.05$) as a *post hoc* test.

Results

Chemical characteristics of treated soils

For pH and EC, an interaction ($P \leqslant 0.05$) between treatments and sampling time was observed. The pH values ranged from 7.9 to 8.3, with organically treated soils showing higher pH values throughout the experiment than mineral fertilized soils. In general, before cultivation and after the second crop EC values in organically treated soils were lower ($P < 0.05$) than in mineral fertilized soil. EC values in organically treated soils diminished significantly with the successive crops (Table 3).

Table 3. Chemical properties in the treated soils (dry weight). (Number in parenthesis indicates standard deviation, $n = 3$).

Treatments[1]/sampling time	pH			EC ($dS\,m^{-1}$)		
	Before cultivation	After 1st crop	After 2nd crop	Before cultivation	After 1st crop	After 2nd crop
MF	7.86 (0.11)a[2]	7.90 (0.02)a	7.69 (0.13)a	1.04 (0.01)c[2]	0.69 (0.07)a	1.76 (0.12)c
PS	8.09 (0.01)b	7.97 (0.02)a	8.02 (0.04)b	0.94 (0.06)ab	0.68 (0.03)a	0.69 (0.01)a
CSFPS	7.99 (0.07)ab	8.02 (0.06)a	8.25 (0.08)b	0. 98 (0.01)bc	0.67 (0.05)a	0.85 (0.01)b
CPS+WS	8.08 (0.01)b	7.95 (0.03)a	8.33 (0.18)b	0.85 (0.04)a	0.67 (0.06)a	0.60 (0.02)a
	C_{org} ($g\,kg^{-1}$)			N ($g\,kg^{-1}$)		
Treatments[1]/sampling time	Before cultivation	After 1st crop	After 2nd crop	Before cultivation	After 1st crop	After 2nd crop
MF	17.5 (0.90)a[2]	18.7 (0.20)b	18.5 (0.80)b	3.6 (0.12)a[2]	3.5 (0.20)b	3.5 (0.35)b
PS	22.5 (0.32)b	14.0 (1.00)a	14.5 (0.50)a	3.6 (0.20)a	3.4 (0.44)b	3.0 (0.10)a
CSFPS	24.6 (0.05)c	20.4 (0.98)b	21.9 (0.10)c	3.6 (0.05)a	3.0 (0.10)ab	2.9 (0.10)a
CPS+WS	23.1 (0.17)b	24.4 (0.60)c	21.4 (0.95)c	3.9 (0.06)a	3.1 (0.13)a	3.1 (0.06)ab

[1] MF: mineral fertilizer treated soil; PS: fresh pig slurry treated soils; CSFPS: soil treated with compost from the solid fraction of pig slurry; CPS+WS: soil treated with compost from a mixture of pig slurry and wood shavings.
[2] For each parameter and sampling time, values followed by the same letter are not significantly different according to Tukey's test ($P \leqslant 0.05$).

The C_{org} content in the compost-treated soils (CSFPS and CPS+WS) was higher ($P \leqslant 0.05$) than that in the soils treated with mineral fertilizer and fresh pig slurry throughout the experiment (Table 3). In organically treated soils C_{org} content diminished with time (PS 35%; CSFPS 11%; CPS+WS 7%). While no decrease in C_{org} content was observed in the MF treated soil (Table 3). No differences ($P \leqslant 0.05$) were found as regards Kjeldahl N between organically and inorganically treated soils before cultivation. However, N content in the organically treated soils decreased from 17 to 21% with the two successive crops, N content in these soils being significantly lower than in MF treated soils after the second crop. A significant interaction between treatments and sampling time was observed for C_{org} and Kjeldhal N.

Crop yield

Broccoli yields (commercial edible part of the plant) ranged from 51,075 to 52,000 $kg\,ha^{-1}$ (fresh weight), while lettuce yields ranged between 20,915 and 23,561 $kg\,ha^{-1}$ (fresh weight). In both crops, no yield differences ($P \leqslant 0.05$) were observed between the different treatments.

Microbial activity and biomass carbon

Microbial biomass C and basal respiration showed an interaction ($P \leqslant 0.05$) between treatments and sampling time (Table 4). Before cultivation, the MF treated soil showed a microbial biomass carbon (C_{mic}) content similar to that of the organically treated soils (Table 4). However, from the end of the first harvest onward all the organically treated soils showed a higher C_{mic} content ($P \leqslant 0.05$) than the MF soil. As regards basal respiration before cultivation, the MF and PS treated soils showed higher ($P \leqslant 0.05$) basal respiration values than those of the compost-treated soils. These values decreased in the former soils during the course of the experiment, basal respiration values in the MF treated soil being, in general, lower ($P \leqslant 0.05$) than those of the organically treated soils at the end of the experiment (Table 4). Between the different organic treatments CSFPS treatment showed the lowest values throughout the experiment.

Enzyme activities

Before cultivation, dehydrogenase activity in the organically treated soils before cultivation was similar or lower than in the MF treated soil. However, this trend was inverted with time (Table 4) and, after the two successive crops, dehydrogenase activity was higher in organically treated soils than in the soil receiving mineral fertilization.

Urease and protease activities showed an interaction ($P \leqslant 0.05$) between treatments and sampling time. Urease activity decreased ($P \leqslant 0.05$) with crop rotation in all treated soils (Table 5). Protease activity was initially higher ($P \leqslant 0.05$) in the MF treated soil than in the soils receiving fresh or composted pig slurry. However, after two successive crops, the organically treated soils showed higher ($P \leqslant 0.05$) values of protease activity than the MF treated soil; this increase with respect to MF treated soil ranged from 183 to 256% (Table 5). All treated soils showed lower values of protease activity after the second crop than before cultivation.

An interaction ($P \leqslant 0.05$) between treatments and sampling time was observed for phosphatase activity. Before cultivation, all treated soils showed similar values of this enzyme but after the two successive crops, the

Table 4. Biomass C (C_{mic}), basal respiration and dehydrogenase activity in the treated soils (dry weight). (Number in parenthesis indicates standard deviation, $n = 3$).

	Microbial biomass C (C_{mic}) (mg C kg^{-1})		
Treatments[1]/sampling time	**Before cultivation**	**After 1st crop**	**After 2nd crop**
MF	313.4 (2.17)a[2]	427.3 (2.66)a	228.8 (2.70)a
PS	258.3 (2.30)a	503.3 (2.90)b	383.2 (3.00)d
CSFPS	320.5 (2.38)a	498.7 (2.10)b	265.9 (2.40)b
CPS + WS	258.2 (3.70)a	519.1 (2.0)b	312.9 (2.0)c
	Basal respiration (mgC-CO_2 kg^{-1} d^{-1})		
Treatments[1]/sampling time	**Before cultivation**	**After 1st crop**	**After 2nd crop**
MF	19.7 (0.52)c[2]	15.3 (0.68)c	6.92 (0.38)a
PS	18.3 (1.05)c	13.7 (0.36)b	11.2 (1.26)b
CSFPS	11.9 (1.78)a	12.3 (0.40)a	8.33 (0.91)a
CPS + WS	14.9 (0.87)b	23.5 (0.32)d	12.06 (1.30)b
	Dehydrogenase activity (ig INTF g^{-1} h^{-1})		
Treatments[1]/sampling time	**Before cultivation**	**After 1st crop**	**After 2nd crop**
MF	28.69 (1.44)b[2]	30.70 (1.54)a	24.39 (1.22)a
PS	27.50 (1.38)b	21.84 (1.80)b	25.51 (1.88)c
CSFPS	21.84 (1.09)a	29.97 (1.50)a	31.08 (1.56)b
CPS + WS	25.51 (1.27)ab	35.39 (1.77)b	35.06 (1.75)bc

[1] MF: mineral fertilizer treated soil; PS: fresh pig slurry treated soils; CSFPS: soil treated with compost from the solid fraction of pig slurry; CPS + WS: soil treated with compost from a mixture of pig slurry and wood shavings.
[2] For each parameter and sampling time, values followed by the same letter are not significantly different according to Tukey's test ($P \leqslant 0.05$).

Table 5. Hydrolase enzyme activities in the treated soils (dry weight). (Number in parenthesis indicates standard deviation, $n = 3$).

	Urease activity (μmol NH_4^+ g^{-1} h^{-1})			Protease activity (μmol NH_4^+ g^{-1} h^{-1})		
Treatments[1]/sampling time	**Before cultivation**	**After 1st crop**	**After 2nd crop**	**Before cultivation**	**After 1st crop**	**After 2nd crop**
MF	2.64 (0.23)b[2]	2.19 (0.26)a	0.87 (0.11)b	3.21 (0.28)c[2]	2.65 (0.21)b	0.64 (0.46)a
PS	2.08 (0.24)a	2.04 (0.15)a	0.57 (0.18)a	2.08 (0.24)a	2.64 (0.46)b	1.54 (0.21)c
CSFPS	2.66 (0.10)b	1.91 (0.31)a	0.82 (0.17)ab	2.47 (0.04)b	2.62 (0.43)b	1.64 (0.38)c
CPS + WS	2.89 (0.03)b	2.04 (0.20)a	0.64 (0.05)a	2.24 (0.03)b	2.23 (0.03)b	1.17 (0.04)b
	Phosphatase activity (μmol NH_4^+ g^{-1} h^{-1})			**β-glucosidase activity (μmol NH_4^+ g^{-1} h^{-1})**		
Treatments[1]/sampling time	**Before cultivation**	**After 1st crop**	**After 2nd crop**	**Before cultivation**	**After 1st crop**	**After 2nd crop**
MF	2.73 (0.74)b[2]	3.14 (0.65)b	1.36 (0.05)a	0.34 (0.04)b[2]	0.46 (0.11)a	0.96 (0.11)
PS	2.77 (0.22)b	3.16 (0.44)b	2.26 (0.11)c	0.26 (0.05)a	0.51 (0.02)ab	1.65 (0.10)b
CSFPS	2.23 (0.10)a	2.75 (0.06)a	2.43 (0.42)c	0.25 (0.03)a	0.53 (0.03)ab	1.84 (0.02)c
CPS + WS	2.53 (0.08)b	2.83 (0.56)a	1.92 (0.08)b	0.24 (0.01)a	0.62 (0.01)b	1.47 (0.16)b

[1] MF: mineral fertilizer treated soil; PS: fresh pig slurry treated soils; CSFPS: soil treated with compost from the solid fraction of pig slurry; CPS + WS: soil treated with compost from a mixture of pig slurry and wood shavings.
[2] For each parameter and sampling time, values followed by the same letter are not significantly different according to Tukey's test ($P \leqslant 0.05$).

organically treated soils showed higher ($P \leqslant 0.05$) values than the MF treated soil, the increase in enzyme activity with respect to MF treated soil ranging from 141 to 178% (Table 5). All values were lower after the second crop than before cultivation. β-glucosidase activity showed an increase ($P \leqslant 0.05$) during the experiment in all treated

soils (Table 5). After the two successive crops, organic amendments favored an increase ($P \leqslant 0.05$) in the activity of this enzyme over mineral fertilization, ranging from 153 to 192%.

Discussion

Physico-chemical and chemical properties

The soil pH was compatible with a healthy vegetal growth since the optimal pH value for broccoli and lettuce growth is in a range of 6.5–8.0[23]. Since the organic amendments had a pH range of 6.7–6.9 and the soil pH was 7.7, a decrease in soil pH with the organic amendments might have been expected. However, soil pH increased, which may have been due to the action exerted by the high $CaCO_3$ and soluble salt content of the pig slurry products derived from the pig diet[24]. Bernal et al.[25] and Whalen et al.[26] also reported that soil pH increases with increasing pig slurry amendment. The EC values observed in the soils were below the $2\,dS\,m^{-1}$ threshold value which indicates a hazardous level of salt concentration in the soil solution. The diminution in the EC values of the organically treated soils with successive crops is attributable to salt leaching through the soil profile[27]. It should be noted that after the second crop the MF soil showed an EC value higher ($P \leqslant 0.05$) than that of the organically treated soils, which can be explained by the successive applications of mineral fertilizer, pointing to the risk of soil salinization with such a practise.

The addition of composts increased ($P \leqslant 0.05$) the soil C_{org} content with respect to the MF treated soil. This is attributable to the organic matter incorporated with the organic amendments as well as to root exudates and vegetal remains, and confirms that the incorporation of stabilized organic amendments has the advantage compared with mineral fertilization of improving the soil organic matter content and contributing to the maintenance of soil humic substance pool and soil fertility[9]. Nevertheless, changes in the quality and quantity of soil organic matter content are difficult to quantify in short-term studies because they are small compared with the large background of organic matter and natural soil variability[28].

The lower ($P \leqslant 0.05$) C_{org} content measured after the first and second crop in the PS treated soil with respect to the compost soils, despite the multi-application of fresh pig slurry, may be attributable to the lower organic matter content of this waste compared with its derived composts and its more unstable character. Data were similar to those indicated by Plaza et al.[29] who observed significant lower C_{org} values in soils amended with pig slurry at $150\,m^3\,ha^{-1}\,yr^{-1}$ than in compost treated soils.

The nitrogen content is one of the most important factors for plant growth, and after the two successive crops, the nitrogen values in some organically treated soils were lower ($P \leqslant 0.05$) than the observed in the MF soil, suggesting a certain depletion of the N incorporated in the soil with the organic amendment. This indicates that another organic amendment or alternative N supply would be necessary after two successive crops before planting a new crop. The decreases observed can be attributed to the loss of NH_3-N by volatilization, N-uptake by crops and NO_3^- leaching. Since all treatments led to similar yields in the two successive crops, it can be stated that a sole application of pig slurry composts was able to provide the nutrients required for this kind of crop. Due to its stable character, organic compost mineralizes slowly, acting as a slow release fertilizer[30].

The possibility of obtaining similar broccoli and lettuce yields by applying one dose of slurry composts as by applying two successive doses of mineral fertilizer clearly represents an economic, energetic and environmental advantage. The addition of fresh pig slurry can also be an effective alternative. However, it does have associated problems, such as producing unpleasant smells, risk for users and environment of contamination by pathogens and opens up the possibility of nitrate contamination[4,31,32]. In addition, it must be added before planting each crop since it does not possess such a high residual nutritional effect as composts[30].

Microbial activity

The incorporation of nutrients with the mineral fertilization as well as the incorporation of easily degradable organic matter and nutrients with the organic amendments stimulated the growth of a soil's indigenous microorganisms[33]; in addition, organic amendments contributed to the microorganisms they contain[9]. Nevertheless, differences between mineral and organic fertilization with respect to the C_{mic} content were not noticeable at the beginning of the first crop, which may be due to the slower availability of the nutrients provided by the composts and/or to the need for a period of time for compost microorganisms to adapt to the new environmental conditions.

After the two successive crops, C_{mic} values in the organically treated soils were higher ($P \leqslant 0.05$) than in the MF soil. This lower C_{mic} value in the MF soil could be due to shortage of available carbon after an initial boost of mineralization activities[34]. Ritz and Robinson[35] and Stevensson and Pell[36] found no consistent effect of mineral N-fertilization on microbial biomass under spring barley and in three Swedish long-term field experiments, respectively. Fresh pig slurry treated soils showed similar C_{mic} values to compost-treated soils. However, it should be borne in mind that compost was only added to the soil once, while PS was incorporated twice. Soil respiration is considered as an useful indicator of microbial activity[37]. Before cultivation, MF and PS treated soils showed higher ($P \leqslant 0.05$) microbial activity values, as estimated by basal respiration, than the compost soils, which may be due to the higher available nutrient content of the mineral fertilizer and fresh pig slurry with respect to pig slurry composts. Although differences between the basal respiration values

of the compost treated soils were not significant, basal respiration tended to be higher in the soil treated with the compost containing wood shavings (CPS+WS). In previous work[8], it was observed that the amount of CO_2 released (microbial respiration) from pig slurry composts with bulking agent was always higher than that of the same composts without bulking agent, suggesting that the higher porosity and improved aeration provided by the bulking agent to the compost as well as the nature itself of this agent (wood shaving) stimulated compost microbial activity.

Metabolic microbial activity was also evaluated by measuring dehydrogenase activity, which is an enzyme involved in the respiratory chains of all microorganisms and has been used to evaluate the overall microbial activity in soils[38]. Before cultivation soil dehydrogenase activity in the MF and PS treated soil was, as observed for basal respiration, similar to or higher than that of compost treated soils, which, as indicated above, can be explained by the higher available nutrient content of the mineral fertilizer and fresh pig slurry compared with pig slurry composts. As the organic matter of compost mineralized and the medium was enriched in available nutrients, microbial activity in compost treated soils increased, all the organically treated soils showing dehydrogenase activity values higher ($P \leqslant 0.05$) than the MF treated soil after the second crop. These results again confirm that organic fertilization has a greater and more durable positive effect on microbial population growth and activity than mineral fertilization.

Enzyme activities

The statistical analysis of some enzymes assayed pointed to significant variations in activity as a function of sampling time. Martens et al.[39] stated that in a soil receiving constant organic amendments, the processes of promoting and suppressing enzyme activities may be balanced.

Urease activity hydrolyzes urea type substrates to NH_4^+[40]. Urease activity was very similar in all treatments, diminishing ($P \leqslant 0.05$) with cultivation in all treated soils, which might be due to the lack of specific substrates and/or the presence of a sufficient concentration of NH_4^+ in the medium making the synthesis of the enzyme unnecessary. The activity detected could be also due to the existence of immobilized enzymes since urease is an enzyme of microbial origin prone to form bonds with soil mineral and organic colloids, thus being protected against denaturization[41,42].

Protease activity hydrolyzes *N*-α-benzoyl-L-argininamide and catalyzes the hydrolysis of simple peptides (dipeptides) to ammonium. Immediately after the incorporation of the different treatments, MF treated soils showed higher protease activity than organically treated soils. This agrees with lower values of C_{mic} and microbial activity (basal respiration and dehydrogenase activity) detected initially in organically treated soils, which may be due to the need for a period of time for microorganisms to adapt to the new environmental conditions. However, after the two successive crops, protease activity was significantly higher ($P \leqslant 0.05$) in the organically treated soils than in the MF treated soil, suggesting a higher amount of specific substrate in the former soils.

Phosphatases play an essential role in the mineralization of organic P to inorganic P compounds available to plants. After the first crop, a general increase in phosphatase activity was observed in all treated soils, which can be attributed to the influence of the crop itself since plants contribute to phosphatase activity[43]. After the two successive crops the compost treated soils showed higher activity than the MF treated soil. Similar results were observed by Dick et al.[44] who observed activity increases in manure treated soils with respect to the control, ranging from 36 to 190%. This can be explained by the higher amount of specific substrate in the organically treated soil and the possible immobilization of this enzyme in the compost organic matrix[45]. Pascual et al.[46] showed that total and immobilized urease and phosphatase persisted in soils for 360 days after compost application.

After the two successive crops, the organically treated soils showed higher β-glucosidase activity than the MF treated soil. The significant degree of activation during cultivations of an enzyme such as β-glucosidase, which is directly involved in the C cycle, is of great importance, since this implies hydrolysis of the C proceeding from the incorporated organic matter and from roots and plant residues remaining after harvest, which provides substrates for β-glucosidase[47]. The C cycle will be activated in the search for equilibrium between mineralization and humification processes.

Conclusions

From this study it can be concluded that both fresh and composted pig slurry can be used as an alternative for mineral fertilizer in horticultural crops since they produce the same yields, providing the nutrients required for crop growth through organic matter mineralization and improving soil microbial community and organic matter (maintains soil quality). However, composts make a more sensible choice than fresh pig slurry because of the smell and risk of pathogen contamination and nutrient leaching derived from uncomposted pig slurry. In addition, due to the gradual mineralization of the compost organic matter as a result of its stable nature, one sole application of compost supplies nutrients to cover the nutrient requirements of two successive crops whereas two successive applications of mineral fertilizer are necessary.

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Periphyton in rice–fish culture system: A case study from Arunachal Pradesh, India

D.N. Das[1,*], S.K. Saikia[1], and A.K. Das[2]

[1]Department of Zoology, Rajiv Gandhi University, Itanagar-791 112, India.
[2]Department of Botany, Rajiv Gandhi University, Itanagar-791 112, India.
*Corresponding author: dndas321@rediffmail.com

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Abstract

The farmers of the Apatani tribe in Arunachal Pradesh, India have been raising a concurrent crop of fish successfully in their mountain valley rice plots for the past 40 years. They follow indigenous rice agronomy, ignoring the use of fertilizers, pesticides and even supplementary feed for the fish reared in the system. However, the yield levels of fish, ranging from 250 to 500 kg $ha^{-1}season^{-1}$, clearly support the role of other available resources within their wet rice fields. The investigation revealed that the rice itself provided the substrates for colonization and growth of periphyton. The colonized periphytic contents (1406–13513 no. cm^{-2} $stem^{-1}$) on rice stems and other natural fish feeds within the system seem to have direct effect in this regard. The Apatani technique of rice–fish integration may be considered as one of the periphyton-based aquaculture (PBA) systems which deserve further research attention.

Key words: Apatani tribe, periphyton, rice–fish system, PBA, biological synergy

Introduction

Periphytic organisms that live attached to surfaces projecting from the bottom of a freshwater aquatic environment generally attain high biomass and contribute up to 80% of the primary production[1,2]. As a food in aquaculture, periphyton may provide 75% metabolic energy to fish[3]. The periphyton have been studied extensively in lakes[4,5], reservoirs[6,7], ponds[8–10], rivers and streams[6,11]. Its potential has also recently been evaluated through periphyton-based aquaculture (PBA) experiments in ponds[9,12]. However, in the wet rice environment, these biotic communities (periphyton) were reported along with plankton[13] and associated algae[14–17], but were rarely related to the contribution in the rice–fish system. Practically, the periphyton component has neither been assessed nor given much importance as a system component in concurrent rice–fish culture in this country or abroad.

An agrarian hill tribe of the Apatani plateau (>1500 m above mean sea level) in Arunachal Pradesh, India has cultured fish in rice fields merged with their traditional agronomic practices over the past 40 years[18]. They stock their flooded rice plots with common carp (*Cyprinus carpio* L.) at fry stages (2.5–3.0 cm) in April–May just 10 days after transplanting the tender and healthy seedlings of local rice cultivars. The farmers do not supplement any feed for the fish but for rice they allow the stubble of the previous crop to rot in the field itself during the fallow period. Monocropping of the fields once in a year with wet rice facilitated such organic fertilization practice. During field preparation, they occasionally use cow dung and farmyard manure. Harvesting of fish is performed either sequentially at a periodic interval or once at the end of the season. The reared fish normally grow up to 480, 250 and 100–120 g, respectively, in culture durations of 5, 3 and 1–1½ months. The farmers assume that the fish keeps the field soil soft and clean thereby yielding better crops of rice. Many farmers also observed that the reared fish actively nibble on submerged rice stems in mornings and evenings of each day, keeping rice stands clean, and also feed on organisms and pollen dropping from the rice canopy.

With the above background, a study on periphytic life forms in rice fish plots of the Apatanis was conducted during three consecutive wet rice seasons of 2001–2003 to confirm farmers' traditional belief and experiences.

Materials and Methods

Samples were collected from rice fields during the rice growing seasons using standard methods for the measurement of field plankton[19]; stem periphyton[14,17,20] and fish gut samples[3] at weekly intervals regularly at morning hours. Randomly, total of 50 liters of field water was

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Table 1. Periphytic organisms on rice stems and in gut contents of *Cyprinus carpio* L. in the rice–fish system.

Rice field	Common in both	Gut content
Spirulina spp.	*Anabaena* spp.	*Microcystis* sp.
Anabaena spp.		*Anabaena* spp. (3)
Oedogonium spp. (2)	*Oedogonium* spp.	*Oedogonium* spp. (2)
Gleocapsa spp.	*Scenedesmus* spp.	*Scenedesmus* spp. (2)
Ankistrodesmus spp.	*Geminella minor*	*G. minor*
Scenedesmus spp.	*Spirogyra* sp.	*Spirogyra* sp.
Chlosteriopsis spp.		
Spirogyra spp.		
G. minor		
Zygnema spp.		
Gomphonema spp. (2)	*Gomphonema* sp.	*Gomphonema* sp.
Cymbella spp.	*Pinnularia* spp.	*Pinnularia* spp.
Diatoma spp.	*Navicula* spp.	*Navicula* spp.
Fragilaria spp.	*Tabellaria flocculosa*	*Selenestrum acuminatum*
Achnanthes spp.		*T. flocculosa*
Navicula spp. (3)		
Nitzschia spp. (2)		
Pinnularia spp. (2)		
Rhopalodia spp.		
Surirella capriconii		
T. flocculosa		
Closterium spp. (7)	*Closterium* spp. (2)	*Closterium* spp. (2)
Cosmarium spp. (9)	*Cosmarium* spp. (4)	*Cosmarium* spp. (4)
Desmidium gravilli	*Pleurotaenium trabecula*	*P. trabecula*
Docidium spp. (2)	*Triplocera gracile*	*T. gracile*
Euastrum spp. (4)	*Euastrum* spp. (2)	*Euastrum* spp. (2)
Pleurotaenium spp. (5)	*Xanthidium spinuosum*	*X. spinuosum*
Staurastrum spp. (3)	*Staurastrum* spp. (3)	*Staurastrum* spp. (3)
Selenastrum gracile		
T. gracile		
Xanthidium spp. (3)		
Arcella spp.	*Arcella* spp.	*Arcella* spp.
Difflugia spp.	*Difflugia* spp.	*Difflugia* spp.
Euglena spp.	*Euglena* spp.	*Euglena* spp.
Anuraeopsis spp.	*Anuraeopsis* spp.	*Anuraeopsis* spp.
Trichocerca spp.	*Trichocerca* spp.	*Trichocerca* spp.
Lecane spp.	*Lecane* spp.	*Lecane* spp.
Colurella spp.	*Colurella* spp.	*Colurella* spp.
		Keratella cochlearis

Numbers in parentheses indicate identified numbers of species under the mentioned genera.

filtered through a 0.20 µm plankton net and preserved in 4% formalin in 25 ml glass vials for laboratory analysis. The submerged rice stems were collected from a depth of 7.0–8.0 cm below the water surface of the field and 5.0 cm above from the field bottom at a constant length of 5.0 cm and preserved in 25 ml culture containing 4% formalin until further processing. Fish were also sampled randomly from the field and the full-length gut from each was dissected out to preserve in 4% formalin for further laboratory analysis. In the laboratory, rice stems were scraped[9] and gut contents were carefully removed[11]. Besides, periphyton was also sampled from the field during early flood, flood and post-flood periods, respectively, following the modified glass slide method[17,21]. For the purpose, glass slides (15 × 35 mm) were used on a specially designed periphyton sampler in view of the shallowness (<40 cm) of the rice field. The sampler was comprised of a 70–80 cm long bamboo stick fitted into the center of a wooden float of area 10 cm^2. The wooden float was equipped with iron nails to hold at least ten (10) glass slides tightly like the blades of fan around it. The samplers were placed into the field canals at the time of transplantation of rice seedlings in the field so that the slides remain submerged under water during the season. The qualitative and quantitative analyses[22] of the samples were carried out to determine the commonness of periphytic members in gut contents of reared fish along with the diversity indices[23–26] for periphytic communities. Identification was performed using standard manuals[27,28] up to the genera level of taxa and wherever possible to the species level.

Results and Discussion

The analysis of gut contents of fish and organisms attached to rice stems in the rice–fish system showed that only 23 genera of periphytic members were common in both, whereas rice stems harbor about 38 genera and the reared fish consumed only 26 genera of the organisms (Table 1). The diversity of planktonic (suspended) forms in the rice field is comparatively less than periphyton (attached forms) on rice stem and also on glass slides (used for quantifying periphyton in relation to time) in the field (Fig. 1). Greater diversity of periphytic life forms was observed on rice stems[17] compared to highest level of diversity as reported[9] on bamboo substrates from the pond PBA systems. Probably the shallow and transparent water of the rice field allowed sufficient light[5] to strike the field bottom and caused more periphyton growth compared to pond systems. Moreover, the periphytic diversity on rice stems throughout the season showed compositional similarity (Fig. 2) with the composition of available field plankton. The investigations clearly showed the richness of the periphytic resources both in abundances (Fig. 1) as well as in diversity (Table 2) in the rice–fish integrated field. The study also revealed that the reared fishes were probably more opportunistic[29] and preferred periphytic forms of feed than suspended or planktonic forms which were available simultaneously within the system.

From the viewpoint of the PBA concept[9,12], the indigenous practice of raising fish in rice adds a new dimension to the rice–fish system. It also explains the

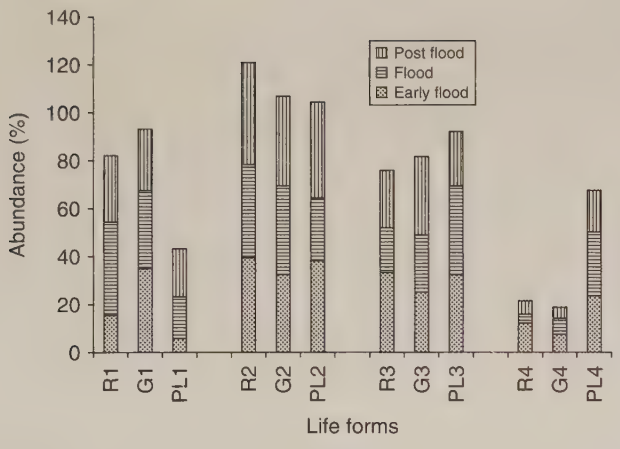

Figure 1. Abundance (%) of periphyton (on rice stems and on glass slides) and plankton (in field water) in rice–fish integrated fields of Apatani Plateau, Ziro. R = periphytic forms on rice stem; G = periphytic forms on glass slide; PL = planktonic forms; 1 = Cyanophyceae; 2 = Chlorophyceae; 3 = Bacillariophyceae; 4 = animalcules.

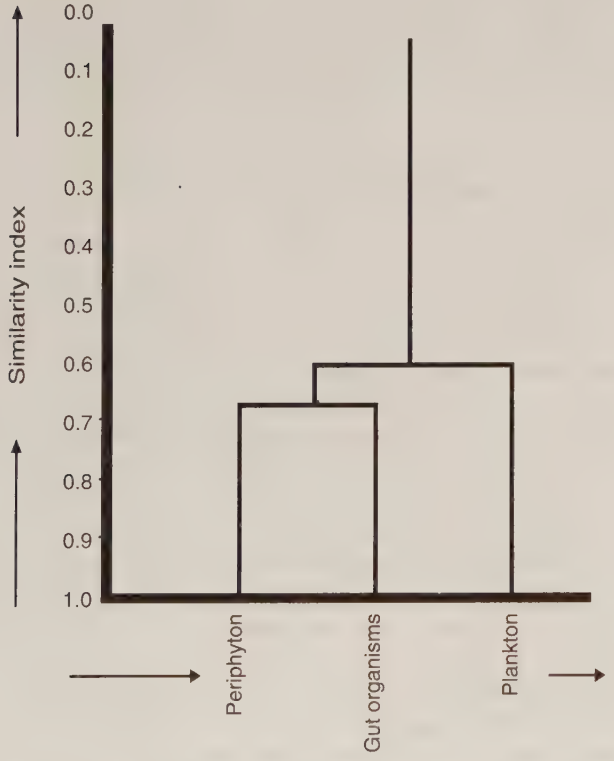

Figure 2. Dendogram showing the relationship among the diversity of periphyton in gut content, field periphyton and field plankton in the rice–fish system.

organic nature of the Apatani system[18] scientifically in regard to production and harvest of fish from their mountain valley rice fields. The waterlogged rice fields, therefore, hold enormous potential to be used as a 'self-substrating PBA' (SSPBA) system for wet rice farmers as a whole. The system also reduces the need for and cost of extra input of substrates[9,10] that are recommended for pond aquaculture.

Table 2. Density and diversity indices for periphyton in different flooding phases of the wet rice field under rice–fish culture at Ziro, Arunachal Pradesh, India.

Flooding phases	Quantity on *Amo* cultivar (units cm^{-2} $stem^{-1}$)	Diversity indices			
		H	D	J	E
Early flood (May–June)	1406	1.16	0.65	0.58	0.66
Flood (July–August)	4960	1.15	0.64	0.57	0.69
Post flood (September–October)	36513	1.14	0.74	0.57	0.69

H = Shannon's' diversity index, D = Simpson's diversity index, J = Shannon–Weiner Evenness, E = Simpson's evenness.

Practically, the substrate facilitates colonization of periphyton in the PBA system[8]. All these functional, ecological and economic linkages of waterlogged rice agroecosystems have made the rice–fish farming technique a sustainable component of small-scale rural aquaculture[30]. Being an important crop diversification option in rice-based farming[31], the system needs intensified research and development of an interdisciplinary approach in rice-growing countries and most particularly in countries like India.

Conclusion

This study demonstrates the advantages of inbuilt biological synergies in a system of agriculture over exogenous energy-intensive inputs of other single-component systems. The study also indicates that periphytic organisms neither interfere with nor harm the rice or fish. Rather, they help in combined production of both in areas where farmers cannot afford increasingly expensive exogenous inputs. The linkages amongst the biological components, namely plankton, periphyton, rice and fish, within the system provide an insight into understanding the whole production process. It clearly supports the concept of integrating aquaculture with wet rice cultivation for sustainable and increased productivity based on biological synergies of more diverse multi-component systems.

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Book Review

World Agriculture and Environment: A Commodity-by-Commodity Guide to Impacts and Practices. By Jason Clay. 2004. Island Press, 1718 Connecticut Avenue NW, Suite 300, Washington DC 20009. 570 p. paper, $45.00, ISBN 1-55963-370-0.

This comprehensive reference book provides a good overview of global agriculture at the end of the millennium. In the introduction, author Jason Clay brings his long experience—in farming, teaching, and government service—into the presentation of a balanced perspective on how production must be balanced with concern for the environment. Now with World Wildlife Fund, he couples a background in economics, anthropology and geography with considerable professional experience in aquaculture and cooperation in the private sector to explore multiple aspects of agriculture and food production. He is particularly effective in discussing the economic and environmental sustainability of the food system, although he also brings in social dimensions such as over-consumption, human obesity, and waste in the system in the North as contributing factors to our global dilemma over food.

In chapter 1, the global trends in agriculture toward specialization and monoculture in an industrial model are discussed. The author avoids providing a strong opinion about this direction in agriculture, but clearly points out the consequences of such development. There is a question about the sustainability of a globalized food system, detailed descriptions of threats of large-scale cultivation of key commodities on the environment, and concern about having such a strong human reliance on a narrow array of food crops. He does present a rather shallow criticism of low-input agricultural methods, and suggests that small farms in fact cause most environmental damage. This contradiction in the book is key to the dilemma faced by all who analyze world food production. Author Clay explores the vertical integration in the food industry, the unfair burden of most risk on the farmer, and inequities in the system. He also identified population increase and expansion onto marginal lands as a priority issue, and suggests that more intensive production on the best lands is essential.

In a discussion of agriculture and the environment, the author's background is displayed to strong advantage as he explores loss of soil and agricultural lands, importance of biodiversity and effects of pollution, scarcity of water and useful energy, and global climate change. These issues must be solved if the human species is to continue to thrive, and the specific questions that are raised as a result of large-scale raising of each of 21 major commodities are discussed in detail.

The major strength of the book is in this group of 21 chapters on commodities, a valuable reference for people who want a quick overview of the current status of production, economics and environmental impacts of these principle enterprises on the global scene. Each chapter provides a map of distribution, useful statistics, an overview of the commodity, profiles of both producing and consuming countries, discussion of different production systems, processing, aspects of marketing, current environmental impacts and alternatives that could mitigate them, and an outlook for the future. Ample references are provided for each commodity to provide credibility for the chapter and lead the reader to a more in-depth review of that topic. The commodities included range from the major cereals and root crops to specialties such as coffee, tea, and cocoa, fiber crops including cotton and wood pulp, rubber, and three animal species—beef, shrimp, and salmon. These are chosen in part because of their current and potential future environmental impact, not just on share of total consumption on a global scale.

For a general reader less interested in specific commodities, it would be useful to skip to the conclusions where the author provides a summary of key issues and recommendations that need to be addressed. These include land use zoning and regulations, retiring marginal lands and improving degraded areas, farming with nature, eliminating subsidies, paying farmers for environmental services, addressing social equity in distribution of benefits, using regulations and incentives to promote better management practices, and improving certification and labeling. This daunting list covers that litany of improvements that are discussed by a number of authors, but this book has the authority of a person who has spent a career looking at environmental impacts and the strength of the chapters that lead up to these conclusions. *World Agriculture and Environment* is an excellent reference book, and the two first chapters and conclusions would be useful for anyone interested in gaining a quick overview of the global production situation in regard to environment. These sections would be appropriate to an introductory class in world agriculture and food systems.

Charles Francis, University of Nebraska-Lincoln, USA.
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Commentary and Responses

Editors' Preface

As the Editor-in-Chief of *Renewable Agriculture and Food Systems* (*RAFS*), I received an e-mail from Alex Avery, Director of Research at the Center for Global Food Issues on 10 September 2007. It read, 'Dr. Doran, as a non-subscriber to *RAFS* I do not know where to submit the following set of misrepresentations and errors in the paper published in July in *RAFS* by Badgley et al. from the University of Michigan. Thus, I am sending it directly to you.'

In response, I stated that his 'critique' of the Badgley et al. paper entitled 'Organic agriculture and the global food supply', which was actually published in June (not July), would be presented as a Commentary critique together with an editorial response from the authors, and those involved in the peer-review process in an upcoming issue of *RAFS*.

The Editorial staff has decided to publish the Avery 'critique' as a Commentary in the Journal with responses from the authors, Catherine Badgley and her co-authors, and William Liebhardt, who were the main subjects of Avery's criticism. Publication of the Commentary and responses is done in the interest of fair play and a desire to provide all viewpoints on the important issue of meeting future food and resource needs as indicated by the Editorial in the June, Vol. 22(2), issue of *RAFS* entitled 'Balancing food, environmental, and resource needs'.

In that Editorial, a paraphrased quote has particular relevance to the current debate: 'Ultimate success in alleviating hunger, malnutrition, poverty and global resource degradation in the technically complex 21st Century will not come solely from intensive input or organic agriculture but rather a hybridization of both approaches.' It is my hope that we can move forward as a civilization as we LISTEN and LEARN from each other with the primary goal of achieving a more sustainable and equitable agriculture, whatever the approach taken.

John W. Doran
Editor-in-Chief, *RAFS*

'Organic abundance' report: fatally flawed

Alex Avery

Director of Research, Hudson Institute's Center for Global Food Issues, Churchville, VA, USA.
September 2007

Commentary

Abstract

Fatal flaws in the recent report from Badgley et al. claiming that organic agriculture 'could produce enough food on a global per capita basis to sustain the current human population, and potentially an even larger population, without increasing the agricultural land base'. Among the serious problems identified: over 100 non-organic yield studies were claimed as organic; organic yields were misreported; false comparisons were made to unrepresentative low non-organic yields; high organic yields were counted 2, 3, even 5 times by citing different papers that referenced the same data; favorable and unverifiable 'studies' from biased sources were given equal weight to rigorous university studies. This report is being submitted to the Editor of the journal, *Renewable Agriculture and Food Systems*, for publication and response. It is only being released in the interest of public debate and discussion during the much-touted 'organic fortnight'.

The recent report from Catherine Badgley et al. at the University of Michigan (*Renewable Agriculture and Food Systems*, June 2007) claimed that 'organic agriculture has the potential to contribute quite substantially to the global food supply' and said, 'organic methods could produce enough food on a global per capita basis to sustain the current human population, and potentially an even larger population, without increasing the agricultural land base'.

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This claim is simply not credible given the following internal fatal flaws:

1. claiming yields from non-organic farming methods as organic;
2. comparing 'organic' yields to non-representative 'non-organic' yields;
3. double, triple, even quintuple counting of organic yields from the same few research projects;
4. omitting non-favorable crop yields while using favorable yields from the same studies;
5. misreporting yield results.

Non-organic Yields Used to Inflate Organic Productivity

In perhaps the most brazen example of research misrepresentation in decades, 105–119 studies claimed as 'organic' by the University of Michigan group were not organic. Only 11–21% of 'developing world' yields cited were from studies actually using organic farming methods. Some 'organic' examples even used genetically modified organisms (GMO) crops; many (if not most) used synthetic fertilizers and pesticides. The researchers did not provide enough detail to determine the exact number of misrepresented studies, but their main source (Pretty and Hine, 2001) stated clearly in their reports that only 14 of 208 studies in their database are 'organic'. The Michigan group relied on 70 of these for their paper. They also labeled as 'organic' 49 yield ratios from the 'System of Rice Intensification' which is not organic. Combined, these represent 79–89% of the 133 'developing world' yield ratios included in the study.

As an example, Badgley et al. claim that organic methods increased Argentine maize yields by 37% (source: Roberto Pieretti in 'Pretty and Hine, 2001'). In fact, this statistic comes from Argentine farmers using herbicides to kill weeds, growing GMO herbicide-tolerant soy, GMO insect- and herbicide-resistant maize, and extensively using synthetic fertilizers and organic-prohibited pesticides. To label these yield gains as 'organic' is absurd (source: personal communication, Mr Roberto Peiretti, past president of the Argentinean No-Till Farmers Association, 31 August 2007).

Another misrepresentation is China maize yield increase of 38%, reported from the East Gansu project run by the Chinese government. The primary source (Pretty and Hine, 2001) reports that 'Grain output and food per capita [in the project area] have increased greatly because of improved crops varieties, runoff harvesting and water-saving irrigation, ***and fertilizers and pesticide use***' [emphasis added].

These facts are made clear in the research reports used in the Badgley et al. report, so their ignoring the non-organic reality of these projects is hard to explain. It is especially hard to explain given supervising author Ivette Perfecto's clear statement in a press release issued by the University of Michigan that 'My hope is that we can finally put a nail in the coffin of the idea that you can't produce enough food through organic agriculture' (press release available at http://www.ns.umich.edu/htdocs/releases/story.php?id=5936; verified 27 September 2007).

False Comparisons with Low Non-organic Yields

The amazingly high yield increases reported in the developing world should have been a red flag that the non-organic yields used in the comparisons were uncommonly low.

For example, Badgley et al. report one study where Peruvian organic potato yields were 340% higher than non-organic (yield ratio of 4.40). Yet the 'higher' organic potato yields (reported as '8000 to 14,000 kg/ha', or 11,000 average) are below the year-2000 average potato yield for Peru, reported by the United Nations Food and Agriculture Organization (FAO) at 11,221 kg/ha in the year 2000. Many farmers in developing countries using non-organic methods report potato yields well above 15,000 kg/ha and non-organic potato yields in developed countries are routinely above 40,000 kg/ha—each considerably higher than the 'high' organic potato yields.

Double, Triple, even Quintuple Counting of Yields from the Same Research Projects

The paper claims to analyze a 'global dataset of 293 examples', yet there are numerous instances of repeated counting of yields from the same long-term studies.

For example, the maize yields from the long-term Farming Systems Trial project conducted by the pro-organic Rodale Institute (Kutztown, PA, USA) are reported four times: once in a 'case study' in a 1989 report from the National Research Council, twice in a report from Pimentel et al., and once in a 2001 newsletter article by Bill Liebhardt.

Soy yields from the same Rodale FST project are reported five times: once by the 1989 NRC report, once by Liebhardt, once by Hanson et al., and twice by Pimentel et al.

Omitting Non-favorable Crop Yields and Cherry-picking Data

The paper reports the favorable yields of specific organic crops from research, while omitting the unfavorable yields of other crops reported in the same research. In addition, non-favorable study results from organic research groups were entirely omitted.

Four different favorable potato yield ratios are cited from one research project in Germany (90–106% of non-organic yields), while unfavorable organic potato yield data (75% of non-organic potato yields) published in the very same journal in which the Badgley paper appeared was omitted! (Gallandt et al. 1998. American Journal of Alternative Agriculture 13:146–161, which is now *Renewable Agriculture and Food Systems*).

The paper cites four separate favorable yield ratios for wheat from the first 3 years of a long-term California research project (McGuire et al., 1998), but they omit the drastically lower organic maize yields from the same project reported in 2004. The non-organic maize yields were 52% higher than the organic from 1996 to 2004. This result in particular calls into question one of the Michigan group's major claims: that organic farming can obtain ample nitrogen by growing off-season green-manure crops to replace the inorganic synthetic nitrogen fertilizer that currently underpins roughly half of global crop production. In this case, the legume crop costs half the ensuing corn crop. Thus, the green-manure strategy, implemented worldwide, threatens a major cropland expansion due to lower per acre yields and the ensuing loss of wildlife habitat and biodiversity.

Moreover, while there were 'no statistical differences in tomato yields among [the different systems]' during those 8 years, conventional irrigated wheat yields were nearly 30% higher than irrigated 'organic' wheat over the same period.

Many of the studies cited by Badgley et al. are from organic activists with a clear agenda in reporting only high organic yields. The Michigan researchers call these sources 'grey literature', but a more accurate term would be 'biased observers with a clear economic and reputational stake in the outcome'.

For example, there are numerous yield ratios gleaned from reports from 'biodynamic' societies such as the Anthroposophic Society, the Institute for Biodynamic Research, and anti-GM/anti-conventional agriculture pressure groups such as Food First.

This clearly skews the results. A recurrent source for 'developed country' yield ratios is an article written by Bill Liebhardt, published in the quarterly newsletter of an organic promotion organization. Liebhardt cites a 0.95 yield ratio for organic maize following a legume–soybean rotation in comparison to continuous maize yields—despite the fact that the same research Liebhardt cites shows that non-organic maize following soybeans out-yields organic by 10–30%. This is a clear case of favoring the organic perspective.

More egregiously, Liebhardt combines tomato yields from two separate projects to claim 'equal' organic tomato yields when the studies he cites found organic tomato yields were significantly lower yielding. In the first 3 years of one project, non-organic tomatoes out-yielded organic by 66%. So in the fourth year, the researchers started giving the organic tomatoes a literal head start by transplanting tomato plants started weeks earlier in a greenhouse—while still using tomato seeds in the non-organic plots. Yet the non-organic tomatoes continued to out-yield the organic by an average of 20% in the following 4 years. So in year 7 of the project, the researchers tripled the amount of poultry manure applied to the organic plots, giving the organic tomatoes 3–4 times more nitrogen than the non-organic. Only after all these changes did the organic tomato yields surpass the non-organic by 9%. Even then, organic fruit quality was lower, used more irrigation water, had far greater weed problems, and cost hundreds of dollars more per acre to grow—losing money without a high price premium.

Misreporting of Yields

The authors simply misreport organic yields compared to conventional in at least one instance. Badgley et al. report that organic apples achieve 100% equal yields (ratio of 1.00) in a study published in *Nature* (Reganold et al. 2001. Nature 410:926–930). The study actually reported that organic apples achieved only 93% of non-organic yields (ratio of 0.93).

Strengthening the case for organic agriculture: response to Alex Avery

Catherine Badgley, Ivette Perfecto, M. Jahi Chappell and Andrea Samulon[1]

University of Michigan, Ann Arbor, MI, USA.

Response

The paper by Badgley et al. (2007), 'Organic agriculture and the global food supply' (RAFS 22(2):86–108), presents the case that organic agriculture has the potential to feed the current human population. This conclusion comes from an analysis of 293 yield ratios comparing organic to non-organic production in studies from around the world. In addition, we present data from temperate and tropical agro-ecosystems showing that leguminous cover crops grown

[1]Current address: Rainforest Action Network, San Francisco, CA, USA.

between normal cropping periods could fix more nitrogen than all the synthetic nitrogen currently in use. Our study demonstrates that farmers, consumers, and policy-makers have substantial viable alternatives about how to feed the world, now and in the future. The potential of organic methods is great enough to merit serious consideration by farmers, extension services, agricultural ministries, and global advisory bodies, such as the United Nations Food and Agriculture Organization (FAO), looking at the food security of their regions or the world.

Alex Avery from the Hudson Institute is spreading false and misleading claims about this study.

Response to Alex Avery

Alex Avery presents five criticisms of the paper by Badgley et al. (2007). We respond to each in turn. Numbered items in *italics* and paragraphs in quotes are from Avery's critique.

1. Non-organic yields are used to inflate organic productivity

> 'In perhaps the most brazen example of research misrepresentation in decades, 105–119 studies claimed as "organic" by the University of Michigan group were not organic.'

In the introduction of the paper, we describe how we use the term 'organic' in our study.

> *The term 'organic' here refers to farming practices that may be called agroecological, sustainable, or ecological; utilize natural (non-synthetic) nutrient-cycling processes; exclude or rarely use synthetic pesticides; and sustain or regenerate soil quality. These practices may include cover crops, manures, compost, crop rotation, intercropping, and biological pest control. We are not referring to any particular certification criteria and include non-certified organic examples in our data.* [p. 87, second paragraph]

We used a broader meaning of organic than that of any particular certification program so that we could legitimately include studies that involve practices that are substantially in the direction of strict organic. These studies are from the developing world, where yield comparisons are otherwise quite scarce.

> 'The researchers did not provide enough detail to determine the exact number of misrepresented studies, but their main source (Pretty and Hine, 2001) stated clearly in their reports that only 14 of 208 studies in their database are "organic".'

The general methods by which farm productivity increased in the case studies documented by Pretty and Hine (2001) include intensification of one component of the farm system (e.g., biointensive vegetable gardens, multilayer tree gardens), addition of a new element (animals or trees), better use of natural capital (water or reclamation of degraded land), new regenerative elements (legumes, integrated pest management), and use of new locally appropriate varieties or breeds (p. 13). The authors state 'By our definition of sustainability, almost all projects have made substantial use of agro-ecological or organic principles in production processes' (Annex B, Part 6). This description persuaded us that the 70 cases we cited from Pretty and Hine were from farms practicing methods close to organic. We did not utilize all of the data in this source; for some crops and management practices, we found more detailed information in other sources. If yield information was not tied to a specific crop in a particular country in a particular location, then we did not include it.

> 'As an example, Badgley et al. claim organic methods increased Argentine maize yields by 37% (source: Roberto Pieretti in "Pretty and Hine, 2001"). In fact, this statistic comes from Argentine farmers using herbicides to kill weeds, growing GMO herbicide-tolerant soy and GMO insect- and herbicide-resistant maize, and extensively using synthetic fertilizers and organic-prohibited pesticides. To label these yield gains as "organic" is absurd'.

The yield ratio for maize from Argentina (1.37) is the correct value cited in Pretty and Hine in Table 14, Annex C. The elaboration of this case study (Annex D, Latin America, No. 1) describes zero-till farming. 'Farmers use a range of Integrated Pest Management (IPM), rotational and precision methods for pest and nutrient management. For example, black oats are now commonly used in the rotation during winter for both soil cover and weed suppression. Other legume cover crops are used to improve nitrogen supplies' (Annex D, p. 109). No mention of genetically modified (GM) crops is given. Avery's claim does not fit the information presented in the report of Pretty and Hine. We did not cite the value for soy from Argentina, even though one is given, since so much Argentine soy is GM.

> 'Another misrepresentation is China maize yield increase of 38%, reported from the East Gansu project run by the Chinese government. The primary source (Pretty and Hine, 2001) reports that "Grain output and food per capita [in the project area] have increased greatly because of improved crops varieties, runoff harvesting and water-saving irrigation, ***and fertilizers and pesticide use***" [emphasis added].'

The example from East Gansu includes the following passage: 'Additional benefits [of more efficient rainfall capture and storage, mulching, multiuse crop products and bi-products for livestock] include reduced soil erosion, decreased pesticide and fertilizer use, increased social capital formation ...' (Pretty and Hine, 2001, Annex D, Asia, example 4). This description indicated to us that these

practices were substantially in the direction of organic methods.

> 'They also labeled as "organic" 49 yield ratios from the "System of Rice Intensification" which is not organic.'

For studies involving the System of Rice Intensification (SRI), the yield ratios that we used were either organic (as described in the sources) or implied to be organic. For studies reporting comparisons between organic SRI and non-organic methods, we calculated our yield ratio based on the comparison between organic and non-organic practices. According to Norman Uphoff, an expert on SRI, the SRI method is usually organic.

We note also the statistical analysis presented in Appendix 1 of our paper. To investigate the possibility that data from Pretty and Hine were biasing the average yield ratio for general food categories, we ran a *t*-test on yield ratios from surveys and unreported methods compared to yield ratios from experiments and quantitative comparisons (see p. 97, column 2 of our article). We performed the *t*-test on data for grains, for which the sample size was largest. (Also, since grains provide most of the calories that people consume, the test matters the most for this food category.) The *t*-test failed to find a statistically significant difference between the average yield ratios for data from surveys+unreported methods and data from experiments+quantitative comparisons. This test demonstrates that the data from Pretty and Hine did not bias our results for the developing world.

In summary, we consider that we explained our use of 'organic' and gathered data consistently with our stated usage.

2. False comparison with low non-organic yields

> 'The amazingly high yield increases reported in the developing world should have been a red flag that the non-organic yields used in the comparisons were uncommonly low.'

As stated in our paper, for the developing world, we compared studies of organic methods of intensification with primarily traditional, low-input agriculture. This kind of agriculture usually does exhibit low yields; our point is that organic intensification will improve them.

> 'For example, Badgley et al. report one study where Peruvian organic potato yields were 340% higher than non-organic (yield ratio of 4.40). Yet the "higher" organic potato yields (reported as "8000 to 14,000 kg/ha", or 11,000 average) are below the year-2000 average potato yield for Peru, reported by the United Nations Food and Agriculture Organization at 11,221 kg/ha in the year 2000. Many farmers in developing countries using non-organic methods report potato yields well above 15,000 kg/ha and non-organic potato yields in developed countries are routinely above 40,000 kg/ha—each considerably higher than the "high" organic potato yields.'

We did not compare our yield ratios to country averages for any food categories, nor do we consider this an appropriate comparison for any of our data. The Peruvian potato examples cited in Pretty and Hine were from high-elevation marginal environments—which were not representative of country average values. (As a side note, the 11,000 kg/ha average reported in Pretty and Hine is statistically indistinguishable from the country average of 11,221 kg/ha—if one were to undertake a serious comparison.) The strength of our analysis is in using the many yield comparisons to evaluate average yield ratios for general food categories. A much larger dataset of a different nature could estimate how much of a particular crop could be grown in a particular country. Hence, this criticism is not valid for our paper.

3. Multiple counting of yields from the same research projects

> 'The paper claims to analyze a "global dataset of 293 examples", yet there are numerous instances of repeated counting of yields from the same long-term studies.'

We were alert to this possibility and weeded out a few replicates at an early stage, then checked again once our dataset was complete. Within a source, we averaged values reported for one treatment method but reported different treatments (e.g., corn/soy versus corn/soy/wheat) separately.

> 'For example, the maize yields from the long-term Farming Systems Trial project conducted by the pro-organic Rodale Institute (Kutztown, PA, USA) are reported four times: once in a "case study" in a 1989 report from the National Research Council, twice in a report from Pimentel et al., and once in a 2001 newsletter article by Bill Liebhardt.'

Rodale's Farm Systems Trial was initiated in 1981. The experimental design was changed several times and stabilized in 1991. Since 1991, the Farm Systems Trial has had three treatments: conventional, organic with manure, and organic with cover crops (Pimentel et al. 2005). The data reported by Pimentel et al. are from 1981–2002; one of the central points of this analysis of 22 years of data for the Farm Systems Trial is that the yields (absolute and relative) from the three treatments have changed over time. The data for each treatment are different. For corn and soy (present in all three treatments), we counted the organic-manure/conventional and the organic-cover crop/conventional as separate values. This is not double-counting, and the values are not the same. The value reported from Liebhardt (2001) is an average of data from studies in seven states, with 69 cropping seasons. One of the sources mentioned is the Rodale study, with data for 1990–1999 via personal communication; none of the other

studies mentioned by Liebhardt for maize are cited by us, although we cite some of the same authors for different studies. The average from Liebhardt is dominated by the non-Rodale studies—hence an example of substantial non-equivalence. The data from the 1989 book by the National Research Council come from Case Study 4, the Kutztown Farm, and more specifically from a study by Culik et al. about this farm. The area evaluated includes land from the Rodale Research Center, the actual Kutztown farm, and land from an adjacent farm. The data come from 1978–1982. The study of Culik et al. could be considered the precursor to the Farm Systems Trial, which was begun in 1981 on the Rodale Research Land. Comparison of the treatments of the Farm Systems Trial (as reported in Pimentel et al. 2005) and the treatments reported from Culik et al. (in the book by the National Research Council) shows that these differ substantially for corn. The Farm Systems Trial follows a rigid rotation pattern in a block design of 24 plots; the Kutztown farm (on a larger land base) uses a variable rotation of corn with hay depending on the weather, weeds, insects, and soil fertility of the specific fields. It is not the same system. It would not be appropriate to average all the data from different treatments. Thus, there is no repetition of data (and all the values differ).

> 'Soy yields from the same Rodale FST project are reported five times: once by the 1989 NRC report, once by Liebhardt, once by Hanson et al., and twice by Pimentel et al.'

With regard to soy yields, values from two different treatments (as explained above) were taken from Pimentel et al. (2005). The data from Liebhardt (2001) are from studies in five states, including the Rodale Farm Systems Trial from 1990–1999. The data taken from the National Research Council are from the Kutztown farm—different land, different years, and different treatment than the Farm Systems Trial. The data from Hanson et al. (1997) are from 1986–1990, under a different rotation schedule than for the years 1991 to the present. Thus, a careful evaluation of the sources shows that there is no replication for these data. Avery's criticism on this point is unfounded.

4. Omitting non-favorable crop yields and cherry-picking data

> 'The paper reports the favorable yields of specific organic crops from research, while omitting the unfavorable yields of other crops reported in the same research. In addition, non-favorable study results from organic research groups were entirely omitted.'

This claim is untrue. An examination of our data shows that there are many low yield ratios, especially for studies in developed countries. For grains, we have yield ratios as low as 0.55 (wheat, Michigan) and similarly low values in other food categories (e.g., 0.55 for tomatoes from Ontario). Some of our low ratios come from papers critical of organic agriculture (e.g., Trewavas, 2004). We made a substantial effort to assemble representative, unbiased samples.

> 'Four different favorable potato yield ratios are cited from one research project in Germany (90–106% of non-organic yields), while unfavorable organic potato yield data (75% of non-organic potato yields) published in the very same journal in which the Badgley paper appeared was omitted! (Gallandt et al. 1998. American Journal of Alternative Agriculture 13:146–161, which is now *Renewable Agriculture and Food Systems*).'

We appreciate learning about the potato study of Gallandt et al. (1998). However, if we add the 0.75 ratio from that study to our dataset on yield ratios, it affects the third decimal place of our average yield ratio for the vegetable food category. Thus, omission of data from this study does not change our general conclusions. As a side note, the potato study documented in Gallandt et al. 1998 (in Maine, USA) was redesigned in 1998 for comparisons based on different soil amendments, different weed and pest management strategies, and different rotations. In summarizing long-term results from the same study, Mallory and Porter (2007. Agronomy Journal 99:501–500) reported that potato yields in 12 of 13 years in amended systems (manure, compost, green manure, with minimal synthetic fertilizer inputs) were equal to or higher (4–55%) than in the conventional fertilizer management system. The soil management system relying more on organic inputs improved soil quality and reduced the year-to-year variability in potato yields. While these data cannot be used to confirm actual yield ratios between organic and conventional management, they do clearly demonstrate the advantage to yield quantity, stability and soil quality of using organic and ecological approaches.

> 'The paper cites four separate favorable yield ratios for wheat from the first 3 years of a long-term California research project (McGuire et al., 1998), but they omit the drastically lower organic maize yields from the same project reported in 2004. The non-organic maize yields were 52% higher than the organic from 1996 to 2004.'

The follow-up study to McGuire et al. (1998) is Denison et al. (2004. Field Crops Research 86:267–277). Mean crop yields of maize in organic versus conventional treatments resulted in a yield ratio of 0.66 for 1996–2002. From the same study, mean crop yields of tomato in organic versus conventional treatments resulted in a yield ratio of 1.11 for 1996–2002. Adding these data to our dataset would lead to a slight decrease in the average yield ratio for grain and a slight increase in the average yield ratio for vegetables (in the third decimal place). Neither change would alter the overall conclusions of our study.

> 'This result in particular calls into question one of the Michigan group's major claims: that organic farming can

obtain ample nitrogen by growing off-season green-manure crops to replace the inorganic synthetic nitrogen fertilizer that currently underpins roughly half of global crop production. In this case, the legume crop costs half the ensuing corn crop. Thus, the green-manure strategy, implemented worldwide, threatens a major cropland expansion due to lower per acre yields and the ensuing loss of wildlife habitat and biodiversity.'

Our calculations were based on green manures grown between normal cropping periods; this approach would not require additional cropland. The proposition that green manures could provide adequate nitrogen fertility for grains and other crops was presented not as a prescriptive statement but as a demonstration of the potential for organic sources of fertility to provide the nitrogen needed to grow crops. This method is working well at the Rodale Farm Systems Trial. We would not expect green manures to work the same way in all other settings, nor for the configuration of the sustainable system to be evident in just a few growing seasons. How well green manures will work under other climates and soils and for other crops requires just the sort of research being conducted in the LTRAS at UC Davis. Other organic methods of fertility management are available as a complement or alternative to cover crops.

'Many of the studies cited by Badgley et al. are from organic activists with a clear agenda in reporting only high organic yields. The Michigan researchers call these sources "grey literature", but a more accurate term would be "biased observers with a clear economic and reputational stake in the outcome".'

Most studies cited are from academics who have the experience and credibility to investigate yield comparisons using acceptable scientific procedures. Most studies are reported in reputable scientific journals, including *Nature*, *Science*, *Field Crops Research*, *Agricultural Systems*, *Livestock Production Science*, *Agriculture, Ecosystems and Environment*, *Meat Science*, *Journal of Sustainable Agriculture*, and *American Journal of Alternative Agriculture* (this journal).

'For example, there are numerous yield ratios gleaned from reports from "biodynamic" societies such as the Anthroposophic Society, the Institute for Biodynamic Research, and anti-GM/anti-conventional agriculture pressure groups such as Food First.'

The few studies from biodynamic research organizations were included only if the experimental design was described and followed standard scientific practices. We declined to include data from such sources when this was not the case. Only one yield ratio was taken from a source published by Food First. This was an edited volume about agriculture in Cuba; the Cuban authors are agronomists. A considerable amount of research in organic methods is being conducted in Cuba; thus we considered the data appropriate for this study. The cited "gray literature" investigators who are committed to organic (and other agroecological) farming methods conducted controlled experiments that have as much scientific validity as properly controlled experiments from researchers committed to conventional agriculture.

'A recurrent source for "developed country" yield ratios is an article written by Bill Liebhardt, published in the quarterly newsletter of an organic promotion organization. Liebhardt cites a 0.95 yield ratio for organic maize following a legume–soybean rotation in comparison to continuous maize yields—despite the fact that the same research Liebhardt cites shows that non-organic maize following soybeans out-yields organic by 10–30%. This is a clear case of favoring the organic perspective.'

For the claims about Bill Leibhardt's research, please refer to his response below.

5. *Misreporting of yields*

'The authors simply misreport organic yields compared to conventional in at least one instance. Badgley et al. report that organic apples achieve 100% equal yields (ratio of 1.00) in a study published in *Nature* (Reganold et al. 2001. Nature 410:926–930). The study actually reported that organic apples achieved only 93% of non-organic yields (ratio of 0.93).'

The figure 93% is mentioned neither in the paper nor in the supplementary information online. Reganold et al. (2001) provide a graph but no numerical data for the yield comparisons between three treatments for apple production. Figure 1 shows that the organic system yielded more than the conventional or integrated systems during 2 years and less during 3 years of a 5-year study. A histogram of cumulative yields over 5 years could be the basis for interpreting organic/conventional as 93%. (Note that the ratio of cumulative yields is not the same as the ratio of yearly averages, which would be more appropriate from this study.) Statistical analysis presented in the paper shows that the organic and conventional yields were statistically indistinguishable. The text states that all three systems gave similar yields (abstract and main text). In the absence of quantitative yield data in either the published paper or supplementary information online, we used a yield ratio of 1.00. Had we used the figure 0.93 instead, the average yield ratio for fruit as a food category for the developed world would have declined by 0.035 to 0.92. This value is the same as the average yield ratio for all plant and animal foods from the developed world ($n = 160$). This change would have negligible impact on our overall results.

Response by William (Bill) Liebhardt

Former Director (now retired) of the Sustainable Agriculture Research and Education Program, University of California, Davis, CA, USA.

Response

My research was initiated because I attended a 2000 meeting in PA where Dennis Avery (father of Alex) was debating GMOs. Dennis Avery made claims in that talk about the yield differential of conventional and organic crops and then went on to say how that yield differential would affect land use. Dennis Avery stated that organic yields were only 55–60% of conventional yields and that 18–20 million acres of wildlife habitat would have to be farmed if high input agriculture were farmed organically. As I listened to his talk I wondered where he got his data or information. I knew of farming systems comparisons around the country and the yield differences were not like that. As soon as his talk was over, I was the first to ask a question and it was this. What is the source of your information showing that organic yields were only 55–60% of conventional? He did not want to answer the question. However, the moderator was a journalist from a Philadelphia paper and he said it was a legitimate question and it should be answered. So Avery said he was told that organic wheat in England yielded only 55–60% of conventional. So that was his source. I thought, this person is going around the country using one data point to suggest how the world should feed itself. I thought that the question of how we feed ourselves is an important one but that it should be based on more information than that. So I decided to gather what information that I could from replicated experiments from around the country and that is what I published. I used numbers that I found in the published reports or what the people running the experiments gave to me. Rather than presenting the actual yield data, I decided to convert everything to a percentage as I thought it would make the comparisons easier to make or see. Alex Avery called me in late December that year and we had a long conversation. I told him that I did this work because of what his father had said and I wanted to present at least some limited information that I knew to exist. I told him that I did not think anyone on either side of this debate should be giving talks about how to feed the world using only one crop in one country. If we are going to propose how to manage the planet, it should be based on more than one crop in one country. I believe it should be based on experimentation in many countries and on many farms in those countries. This is too big a question to be left to what a person hears about one crop in one country.

I would now like to deal with Alex Avery's comments in his letter. In the case of the corn comparison, the data are from replicated experiments in seven locations in the United States over a total of 69 years. Organic corn yielded 94% of the conventional corn. Most of this work is from university sources.

Avery is incorrect here in some of his statements regarding the tomato research. What he says about transplanting is correct. This is a farming systems comparison. The experiment had two conventional farmers and two organic farmers as advisors to address farming practices. From a farming perspective, it put the organic treatment at a disadvantage in the early years by planting very early in the season using the direct seed method. It resulted in more weed problems and less nitrogen in the vetch cover crop. The changes were made to make the system perform better. Using transplants also delayed the planting date and allowed the vetch cover crop to accumulate more biomass and N which helped the system perform. The variety also had to be changed due to using the transplants which reduced the cost of seed. All changes were made with the idea of using the best farming practices for that system as that was the philosophy behind this research.

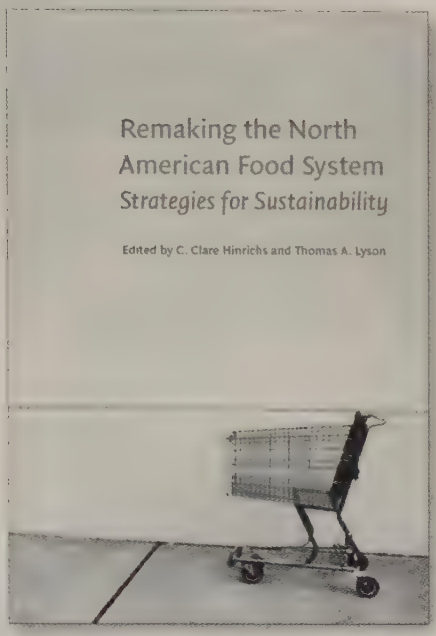
The higher use of irrigation water in organic treatments was a result of better soil quality in the organic plots. The practice was to irrigate everything the same but because the water infiltration rate and water-holding capacity was higher, it could be irrigated longer without having standing water. There were changes in the irrigation after this was observed later on. In the winter, when there was heavy rainfall, the organic plots would not have standing water; however, the conventional plots did. You did not need a plot diagram to identify the organic plots.

Weed problems were greater in the organic treatment. Research is needed in this area. I do not know about the quality information Alex Avery writes about. I know of work on an experiment that shows that antioxidants are higher in the organic treatments. This research has been published by Mitchell et al. (2007. Journal of Agricultural and Food Chemistry 55(15):6154–6159). The work showed that 10-year levels of quercetin and kaempferol in organic tomatoes were 79 and 97% higher than those of conventional tomatoes. The levels of flavonoids increased over

time in the organic treatments, showing that as the soil quality changes so does the tomato quality. The levels of flavonoids did not vary significantly in conventional treatments over the same years.

Finally, the yield differential. Dr Ford Dennison was the PI and I asked him for yield information and told him what I was trying to do. He gave me the percentage yield information and so I used what he provided.

The economic analysis is done with the organic premium because that is part of the system in the real world and the researchers are trying to provide accurate information about system performance.



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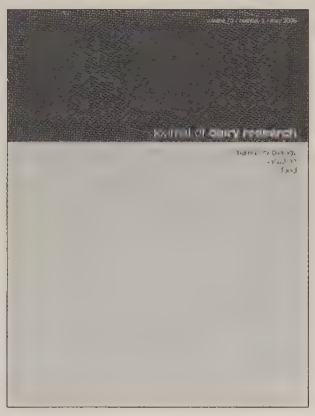

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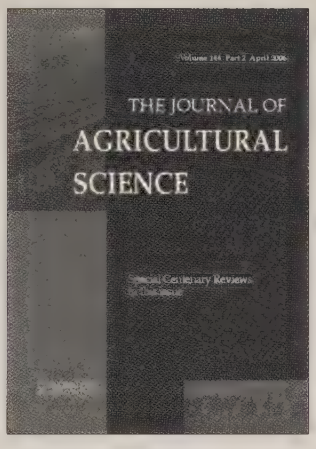

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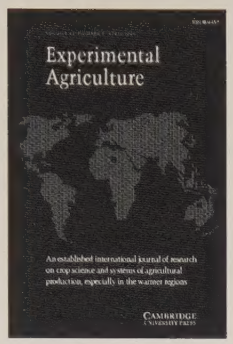
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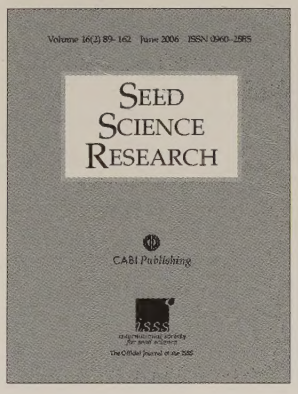

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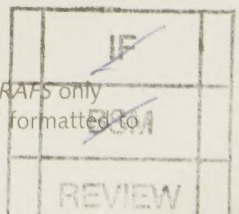

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